Persistent termini of 2004- and 2005-like ruptures of the Sunda megathrust

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Auxiliary Material

Introduction

This Auxiliary Material contains detailed discussions of our study sites and of each coral head analyzed. We methodically describe the Bunon sites (Text S1 and Figures S1–S12) and Pulau Penyu site (Text S2 and Figures S13–S18), and we explain the construction of relative sea-level histories, considering multiple scenarios where data are ambiguous. Supplementary tables provide details on the 14 coral heads used in our study, plus two additional heads from the Ujung Lambajo auxiliary site (Table S1); complete results of U-Th dating analyses on all fossil coral samples (Table S2); dates of presumed uplift of individual coral heads (Table S3); and inferred dates of uplift events determined by calculating weighted averages and considering all information at each site (Table S4). Northern Simeulue sites are described in similar detail in an earlier paper [*Meltzner et al.*, 2010a].

Section S1. Results from the Bunon (BUN) Sites

The Bunon site sits on a broad promontory along the southwest coast of Simeulue, ~10 km south of the center of the island, near Bunon village (Figure S1). As we will discuss, the site was uplifted 65–80 cm during the 2005 earthquake but experienced little vertical change in 2004. Thus, at least for the 2004–2005 sequence, Bunon has acted as part of the southern Simeulue patch and has been independent of northern Simeulue. In addition, Bunon rose ~20 cm during the M_W 7.2 earthquake of 2 November 2002, which had a locus of deformation centered ~15 km to the west-northwest, and up to 10 cm during the M_W 7.3 earthquake of 20 February 2008, centered ~30 km to the west-northwest [*Meltzner et al.*, 2010b].

The Bunon site consists of two subsites: BUN-A is the primary site, and BUN-B is a subsidiary site ~1.8 km to the west-northwest. Both subsites have abundant modern heads (i.e., coral heads that were living at the time of the 2004 and 2005 earthquakes), although none of the modern heads had records of relative sea level extending back more than ~25 years. In addition, the BUN-A site has multiple generations of large fossil microatolls (i.e., microatolls that died long before 2004, possibly in prior uplift events) from the 9th–11th and 14th–16th centuries AD. A total of three modern and seven fossil coral microatolls—all of the genus *Porites*—were sampled from the BUN sites; all but one modern head originated from site BUN-A (Table S1).

Of the sampled fossil microatolls from Bunon, six are from overlapping generations that combine to provide a continuous history of relative sea level at the site from the early 14th to the late 16th century. This time period encompasses a 14th–15th century continuous record from sites on northern Simeulue, over the 2004 patch [*Meltzner et al.*, 2010a], allowing us to compare the behavior of the two sections of the megathrust for the duration of the overlap. The seventh fossil head from Bunon provides a discrete, older record that ends in the early 11th century. This, too, overlaps with observations on northern Simeulue [*Meltzner et al.*, 2010a], providing another window to examine the simultaneous behavior of the two portions of the fault. Comparison of the Bunon and northern Simeulue records reveals strikingly disparate relative sea level histories for the two parts of the island: during those parts of the record that overlap, all ruptures observed as significant uplifts at one end of the island had little effect at the other end.

1.1. Vertical Changes since 2004 at the Bunon Sites

1.1.1. Coseismic change in 2004

Field observations by K. Sieh in mid-January 2005, observations by R. Briggs of freshly uplifted microatolls in early June 2005, and conversations with local villagers and fishermen in 2005 and 2006 all suggest there was little if any vertical change at Bunon in the 2004 earthquake. Perhaps as much as a decimeter or two of coseismic subsidence in December 2004 went unrecognized, but our own coral microatoll cross-sections (Figures S2–S4) preclude uplift in late 2004.

1.1.2. Coseismic change in 2005

Briggs et al. [2006] reported 47 ± 16 cm (2σ) of uplift in 2005 at their site RDD05-L, which corresponds to our site BUN-B. As described by *Meltzner et al.* [2010a], this value was determined by comparing the pre-uplift highest level of growth (HLG, the highest coral that was alive immediately before the uplift) on *Porites* microatolls at the site with the lowest astronomical tide (LAT, the lowest tide level that can be predicted to occur under average meteorological conditions); this method incorporated a tide model, but (as discussed by *Meltzner et al.* [2010a]) the authors at the time were unaware of the magnitude of sea level anomalies (SLAs, misfits between tidal predictions and observed sea surface heights) in the region, and their calculation did not incorporate corrections for SLAs. Redoing that calculation following the methodology of *Meltzner et al.* [2010a], with the original field measurements, an updated tide model [*Egbert and Erofeeva*, 2002; *Agnew*, 1997], corrections for documented SLAs [*Archiving Validation and Interpretation of Satellite Oceanographic Data [AVISO]*, 2010], the revised correction for the difference between *Porites*'s highest level of survival (HLS, the limit above which any living coral would have died due to exposure) and extreme low water (ELW, the lowest water level attained over a period of time, taking into consideration SLAs) [*Meltzner et al.*, 2010a], and an appropriate inverted barometer correction [*Wunsch and Stammer*, 1997; *Meltzner et al.*, 2010a], results in a higher estimate of 64 ± 8 cm. This value represents the net vertical change that occurred at BUN-B between late 2004 and 2 June 2005; if interseismic and postseismic changes were negligible, the coseismic uplift in March 2005 would equal this value, or, if slight subsidence occurred there in December 2004, the March 2005 uplift would be slightly more.

In June 2006, we measured the uplift at site BUN-A using two separate methods, both described in detail by *Meltzner et al.* [2010a]. By surveying the water level relative to pre-uplift HLG and tying the water level to ELW, we determined the net uplift as of June 2006 at BUN-A to be 81 ± 8 cm. At the same time, by comparing the pre-uplift HLG to the post-uplift HLS, we determined the 2005 diedown to be 77 ± 6 cm; correcting that value for the fact that ELW during the period between the March 2005 earthquake and the June 2006 measurement was 3 cm higher than during a similar period prior to the March 2005 uplift yields an uplift estimate of 80 cm, essentially identical to the first measurement. The ~15-cm larger value at BUN-A in June 2006 than at BUN-B in June 2005 was probably mostly or entirely due to the BUN-A site's greater proximity to the 2005 source (Figure S1), although we cannot preclude minor postseismic uplift during the year between the two measurements.

1.1.3. Interseismic stability in 2006–2007

In July 2007, we re-measured the uplift at site BUN-A using the same two methods. By surveying the water level relative to pre-uplift HLG and tying the water level to ELW, we determined the net uplift as of July 2007 to be 83 ± 8 cm. Separately, comparing the pre-uplift HLG with post-uplift HLS and correcting for the difference in ELW prior to the 2005 earthquake and prior to the 2007 measurement again yields an uplift estimate of 80 cm. Together, these values indicate that any vertical change between June 2006 and July 2007 was insignificant.

1.1.4. Coseismic change in 2008

In January 2009, nearly a year after the 20 February 2008 M_W 7.3 Simeulue earthquake, we independently re-measured the net uplift (since 2004) at both BUN-A and BUN-B, again by comparing the pre-2005 HLG with ELW at both sites. At BUN-A, we estimated the net uplift to be 80 ± 8 cm, nearly identical to the 2006 and 2007 estimates; this suggests there was little if any change there during the 2008 earthquake. At BUN-B, we estimated the net uplift to be 72 ± 8 cm, consistent with the spatial trend of decreasing uplift to the northwest, but slightly larger than the uplift measured there in June 2005. This suggests ~8 cm of uplift at BUN-B in 2008.

Additionally, at BUN-A, we observed dead patches on the uppermost ~1 cm of the highest knobs of a few living lobate microatolls during our visit in 2009. (Living corals were not found at BUN-B.) Based on the dead patches' appearance, we judged that this minor diedown had occurred within the previous year. If this minor diedown was due to a relative sea level lowering, then, correcting for the fact that ELW during the period between the February 2008 earthquake and the January 2009 measurement was 7 cm higher than during the year preceding the 2008 earthquake, this implies ~8 cm of uplift at BUN-A in 2008. This is similar to the uplift estimated at BUN-B, but it disagrees with the measurements mentioned earlier that suggested little change (or slight subsidence) at BUN-A between 2007 and 2009. The most straightforward interpretation is either that the actual uplift at BUN-A in 2008 was closer to 3 cm (an average of the two measurements), or that an ~8 cm coseismic uplift was followed at BUN-A by a comparable amount of postseismic subsidence.

1.2. Modern Paleogeodetic Record at the Bunon Sites

Two modern microatolls were slabbed at the BUN-A site, and a third modern microatoll was slabbed at BUN-B. At BUN-A, the BUN-1 microatoll was selected for slabbing because of its nearly perfect radial symmetry and pristine condition, and the BUN-2 microatoll was selected because it appeared to have a longer record. At BUN-B, the BUN-10 microatoll was slabbed in the hope of obtaining a clearer record of the outermost few bands (within which there were irregularities on BUN-2) and in the hope of extending the record of BUN-2 farther back in time. As with other heads in this study, we followed the methodology for slab extraction and analysis described by *Meltzner et al.* [2010a]. Figures S2a, S3a, and S4a show the interpreted cross-sections of slabs BUN-1, BUN-2, and BUN-10, respectively.

1.2.1. Diedowns and causes

BUN-1 began growing in the early 1980s and first recorded an HLS "hit" in late 1997. BUN-2 probably began growing in the 1960s and recorded its first "hit" in late 1982. BUN-2 recorded additional HLS diedowns in late 1986, late 1989, and late 1991. Both heads recorded the late 1997 diedown, as well as subsequent diedowns in late 2002, late 2003, and ultimately early 2005, when the diedown was sufficient that the entirety of both corals died. BUN-10 began growing around 1970 and, like BUN-2, first recorded an HLS "hit" in late 1982. (We were unsuccessful at extending the record of BUN-2 back farther in time.) BUN-10 recorded additional HLS diedowns in late 1988 / early 1989, late 1989 / early 1990, late 1991 / early 1992, late 1997, late 2002, late 2003, and ultimately early 2005, when the coral died entirely.

Except for the diedowns in late 1988, late 1989, late 2002, and early 2005, all of these are seen repeatedly on northern Simeulue [*Meltzner et al.*, 2010a]. The minor diedowns that are seen both on northern Simeulue and at Bunon probably resulted from broad transient oceanographic lowerings. In particular, the two largest of these—in late 1982 and late 1997—coincided with strong positive Indian Ocean Dipole (IOD) events [*Rao et al.*, 2002], which correlate with lower sea surface heights off the west coast of Sumatra [*Taylor et al.*, 1987; *Woodroffe and McLean*, 1990; *Brown et al.*, 2002; *van Woesik*, 2004; *Meltzner et al.*, 2010a]. (Indeed, the late 1997 diedowns, which occurred during the era of satellite altimetry, can be attributed wholly to documented SLAs around Simeulue [*Archiving Validation and Interpretation of Satellite Oceanographic Data [AVISO]*, 2010], without a need to invoke any other explanation.) We attribute the 2002 and 2005 diedowns to tectonic uplifts (earthquakes) that were spatially restricted to areas south of northern Simeulue. The causes of the 1988 and 1989 diedowns are unclear, but both were quite small, affecting at most the uppermost few millimeters of the head (the 1988 diedown is seen only on BUN-10).

1.2.2. Coseismic uplift in 2002

Corals at both BUN-A and BUN-B, and at other sites along the west coast of central Simeulue, record moderate diedowns in late 2002, around the time of a M_W 7.2 megathrust rupture in about the same area [*DeShon et al.*, 2005]. At BUN-A, the 2002 diedown ranges from 16 to 21 cm. In slab BUN-10 (from site BUN-B), the 2002 diedown is only 10 cm, but this is not reflective of the actual diedown at BUN-B or even on the head: within the area of the BUN-10 slab, the head's outer rim (which grew upward following the 1997 diedown until the 2002 diedown) was stunted; that same rim was as much as ~9 cm higher elsewhere on the head, and coeval features on other heads at the site were likewise ~9 cm higher. Thus, the diedown at BUN-B is closer to ~19 cm.

A similar, perhaps more robust calculation of uplift during the 2002 earthquake is based on the relative elevations of the post-1997 HLS and the post-2002 HLS on each head. At BUN-A, post-2002 HLS is 7–12 cm lower than post-1997 HLS; at BUN-B, post-2002 HLS is only 5 cm lower. Considering that ELW in the months following the November 2002 earthquake was 13 cm higher than during the 1997–1998 IOD, one can add that amount to the difference, which yields estimates of 20–25 cm and 18 cm net uplift between the end of 1997 and the end of 2002 at BUN-A and BUN-B, respectively. If there were a few centimeters of interseismic subsidence at the sites between 1997 and 2002 (see Section 1.2.3), then the 2002 coseismic uplift would be a few centimeters more than those stated values at the two sites.

About a year after the late 2002 diedown, in late 2003 or early 2004, all the heads at Bunon experienced a second, smaller diedown. At both BUN sites, the diedown was 2–3 cm, down to levels 1–2 cm lower than the post-2002 HLS. However, ELW in early 2004 reached 6 cm lower than it had in the six months following the November 2002 earthquake. That the late 2003 / early 2004 diedown wasn't more substantial is a little surprising and may hint at several centimeters of postseismic subsidence following the 2002 uplift.

1.2.3. Interseismic subsidence

The microatoll cross-sections also provide information on interseismic subsidence rates. A time series of HLG and HLS is plotted on Figures S2b, S3b, and S4b for BUN-1, BUN-2, and BUN-10, respectively. Following the methodology of *Meltzner et al.* [2010a], we attempt a linear least squares fit to the data, using the head's HLG in the years prior to each diedown, but omitting data prior to the head's initial diedown. For sites in central Simeulue, we also exclude data following the 2002 earthquake, because those elevations are affected by coseismic uplift (we are interested in the interseismic rate prior to that uplift), and we treat 1998–2002 data with caution, because, following the large IOD-induced diedown in 1997, it is not clear whether heads had grown back up to near their theoretical HLS prior to the 2002 uplift.

The limitations on this method preclude a fit to the data from BUN-1, which has only a single usable datum prior to the 2002 uplift, and render fits on BUN-2 and BUN-10 questionable. The linear least squares fit for BUN-2 suggests an average interseismic submergence rate of 5.6 mm/yr over the period 1986–2002 (Figure S3b), but considering only 1986–1995, that rate increases to 7.3 mm/yr (not shown). Correcting for a 2 mm/yr eustatic sea level rise [*Meltzner et al.*, 2010a], these correspond to tectonic subsidence rates of 3.6 and 5.3 mm/yr, respectively, for

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1986–2002 and 1986–1995. For BUN-10, the least squares fit suggests an average interseismic submergence rate of 4.7 mm/yr over 1988–2002 (Figure S4b), or a much larger 10.9 mm/yr over 1988–1997 (not shown). Again, correcting for eustatic sea level rise, these rates correspond to tectonic subsidence rates of 2.7 and 8.9 mm/yr, respectively, for 1988–2002 and 1988–1997. The substantial sensitivity of the rates upon the timespan examined, and the large scatter among these rates, suggest that we are not sampling over long enough periods for these rates to be significant.

1.3. Fossil Paleogeodetic Record at BUN-A

With a few exceptions, most of the fossil microatolls at BUN-A can be divided into two populations based on their morphologies. One sizable population consists of large cowboy hat or sombrero-shaped microatolls. The centers of these heads are either hemispheres or cup-shaped microatolls in their own right, with upper surfaces rising toward the outer rims of the inner heads. As these heads grew, their HLS suddenly dropped to lower levels: the inner heads are surrounded by much lower brims, which themselves rise very gradually (with gradients lower than on the inner parts of these heads) toward their outer perimeters. For clarity, we will refer to the initial large diedown as the inner diedown, and the final death of these sombrero-shaped heads as the outer diedown. The second population of fossil microatolls at BUN-A has more conventional cup-shaped morphologies, except for an exceptionally pronounced upward step in their outward growth, suggesting a 20–25 year period of accelerated interseismic subsidence amidst a much longer period of steady, slow relative sea level rise.

1.3.1. 14th–16th century record at BUN-A

1.3.1.1. "Sombrero-shaped" generation of microatolls

In the field, we decided to take slabs from three of the sombrero-shaped microatolls. We sampled BUN-7 (Figure S5) because it had a beautifully preserved inner head with stairstepping concentric rings that record a century of initially slow, and then more rapid, relative sea level rise. The uppermost part of the crown of this inner head had sustained significant erosion, and in places it appeared as though parts of the upper crown had been chiseled off prior to our visit, but this head was still in better condition than most in the population. The main problem with BUN-7 was that its outer brim had broken off from the inner head, and it was not clear in the field how the outer brim fit back onto the inner head. The inner head had also tilted, but we corrected for the tilting by carefully surveying each ring, which was necessarily originally horizontal.

Fortunately, the outer brim of a nearby head with a similar morphology had remained intact. The inner part of this nearby head (BUN-8) and its uppermost crown were much more extensively eroded than the corresponding portions of BUN-7, but the similarity of the two heads suggested that the outer brim of head BUN-8 could serve to extend the record of the BUN-7 slab. The slab of BUN-7 spans the entire radius of the inner head of microatoll BUN-7, and the slab of BUN-8 (Figure S6) extends from the outer edge of the inner head through the low brim of the microatoll. Even prior to confirmation by U-Th dating analyses, we anticipated that these two slabs could be combined to form a single continuous record of relative sea level.

The third sombrero microatoll (BUN-6; Figure S7) had a hemispherical center and was much more eroded than BUN-7 or BUN-8, but its brim was considerably thicker (in both vertical and horizontal dimensions) than those of BUN-7, BUN-8, and most other heads in the population. The greater vertical thickness of the BUN-6 brim is consistent with a deeper substrate in that vicinity, which could have allowed BUN-6 to survive a small diedown that completely killed shallower heads, including BUN-7 and BUN-8. This interpretation implied to us in the field that BUN-6 contains a part of the sea level record beyond that recorded by BUN-7 or BUN-8.

A fourth head, BUN-5 (Figure S8), also belongs to the sombrero generation, although this association was not evident until revealed by U-Th dating analyses. BUN-5, which was mostly buried in the pre-2005 beach berm until we dug it out, captures the last few decades of growth of the inner, higher parts of the sombrero heads, just prior to the inner diedown. BUN-5 started growing decades (to nearly a century) after the more recognizable sombrero-shaped microatolls in the population, so its record is much more brief; furthermore, it was not tall enough to survive the inner diedown, so BUN-5 has no outer brim. BUN-5 is very well preserved, however, and its record spans the time period of the eroded crowns of BUN-7, BUN-8, and the other sombrero heads; BUN-5 thus adds critical data to that portion of the HLS record.

1.3.1.2. Dating results: "sombrero-shaped" generation (preliminary discussion)

One sample from BUN-5, two from BUN-6, three from BUN-7, and two from BUN-8 were dated by U-Th analysis (Tables S2–S3). As expected, the dates indicate these heads were coeval. Most of the dates agree and indicate these four heads span the 14th–15th centuries AD. The weighted means of the dates from BUN-5, BUN-7, and BUN-8 all suggest the inner diedown occurred in the 1420s–1430s, with uncertainties of one or two decades (Figures S5a, S6a, S8a). The interpretation of the dates on BUN-6 is less straightforward (Figure S7a), but that slab also must have spanned the 1420s and 1430s. Further interpretation of the dates on these heads is deferred to Sections 1.3.1.10 and 1.3.1.12.

1.3.1.3. Inner diedown ambiguity on BUN-8, and plausible interpretations

Although there was little ambiguity in the field that heads BUN-7 and BUN-8 were coeval and that the brim of BUN-8 extended the record of the inner head of BUN-7, there is an irregularity in the morphology of BUN-8 around the time of the inner diedown that suggests the "inner diedown" might itself consist of multiple diedowns. To be clear, none of the microatolls slabbed at BUN-A require anything more than a single diedown at about that time; however, *either* a complicated growth history (with two or more closely timed diedowns) or a complicated erosional history (with an irregular erosional pattern) must be invoked to explain the morphology of BUN-8 around the time of the "inner diedown."

Probably the simpler interpretation (hereafter, Scenario 1) is that there was a single large diedown (the "inner diedown") around the time of interest. In Scenario 1, the inner diedown is seen clearly in the BUN-8 cross-section (Figure S6a) as a growth unconformity at the beginning of the growth band labeled "1422" in blue, and it is the same diedown that caused the big diedown of the BUN-7 slab. If this scenario is correct, the inner, upper part of BUN-8 would have grown outward as far as the blue dash-dotted line on Figure S6a, but, as indicated by the blue labels on Figure S6a, that inner, upper part of BUN-8 would have eroded back over the ensuing centuries from the blue dash-dotted line to its present perimeter. Scenario 1 thus requires that 10 bands have been completely eroded from the upper part of BUN-8. While such erosion cannot be precluded, it would be a little surprising, given both the comparatively good preservation of the head's brim and the observation that the head is still radially symmetric: if as many as 10 bands have been completely eroded from the upper part of the slab, it would be unexpected for the inward erosion to have been uniform from all directions and for the brim to be so well preserved. These concerns lead us to consider an alternative (dual diedown) hypothesis.

An alternative interpretation (hereafter, Scenario 2) suggested by the morphology of BUN-8 is that there were two diedowns less than 10 years apart, around the time of interest. The first of these two diedowns was by far the largest and is considered the "inner diedown"; the second diedown, 7–9 years later, was much smaller and is less noteworthy, except for the fact that it is far better preserved and much more obvious in the BUN-8 slab. In Scenario 2, the inner diedown (which caused the big diedown of the BUN-7 slab) occurred within a year or two of the growth band labeled "1417" in red on the BUN-8 cross-section (Figure S6a). The growth unconformity that would have formed at the time is no longer preserved in the slab but probably originally existed several centimeters above what remains of the "1417" (red) band. About 8 years later, at the beginning of the growth band labeled "1425" in red, a second, smaller diedown occurred, and its associated growth unconformity is preserved in the slab (Figure S6a). If this scenario is correct, the inner, upper part of BUN-8 would have grown outward only roughly as far as the red dash-dotted line on Figure S6a, and a more typical amount of erosion (~2 growth bands, or ~4 cm) would have ensued on the upper part of BUN-8.

The primary differences in the implications of the two scenarios lie in the magnitude of the inner diedown (the amount of the diedown would be slightly less in Scenario 2; see Sections 1.3.1.11 and 1.3.1.13) and in its timing (Sections 1.3.1.10 and 1.3.1.12). Unfortunately, the coeval slabs from BUN-A do not distinguish between the two scenarios; BUN-7, BUN-5, and BUN-6 are consistent with either. BUN-5 was sufficiently short that even the inner diedown implied in Scenario 2 would have killed BUN-5 entirely; similarly, the slab of BUN-7 (the portion of the head we collected, x-rayed, and examined in detail) would not have recorded a later diedown. And BUN-6 is sufficiently eroded that, had dual diedowns occurred, they would now be indistinguishable.

1.3.1.4. Original elevation of BUN-8

Although the BUN-8 microatoll did not appear to be tilted, evidence from the site suggests it had settled by 5–10 cm. First, although the brim of BUN-7 had separated from the inner head and the inner head had tilted, BUN-7's brim was not obviously tilted itself, and our careful surveying showed that it was consistently 5–10 cm higher than the brim of BUN-8. Second, in addition to BUN-7 and BUN-8, we surveyed the elevations of a number of the sombrero-shaped microatolls at BUN-A; several of these had intact, untilted brims. The highest of these brims was at the same level as BUN-7, 5–10 cm higher than the brim of BUN-8. If the highest untilted microatolls of a particular vintage best approximate the HLS at that time, and if all lower microatolls of equivalent age had settled, then the straightforward inference is that BUN-8 had settled by 5–10 cm since it grew. The elevations shown on Figure S6b are those surveyed in the field; however, BUN-8 will be shown in subsequent figures at a restored elevation, 10 cm higher.

1.3.1.5. "Cup-shaped" generation of microatolls

We collected two slabs from the population of cup-shaped fossil microatolls with a pronounced upward step. BUN-3 (Figure S9) was the most well preserved of a cluster of similar tilted heads growing ~200 m northeast of the other slabbed heads at the site. BUN-4 (Figure S10) grew apart from the main BUN-3 population and was mostly buried in the pre-2005 beach berm (along with BUN-5) when we found it. The morphology of BUN-4 was similar but not identical to that of BUN-3, so it was not obvious in the field that they belonged to the same generation.

1.3.1.6. Dating results: "cup-shaped" generation (preliminary discussion)

Six samples from BUN-3 and one sample from BUN-4 were dated by U-Th analysis (Tables S2–S3). The results indicate these heads overlapped, spanning the 15th–16th centuries AD (Figures S9a, S10a). At face value, the dates also suggest the earlier part of BUN-3 overlapped with the later years of BUN-8 and BUN-6; the same might be true for BUN-4. Given the overlaps suggested by the raw dates, we next examine the heads' morphologies to determine which overlap scenarios are possible. Further interpretation of the U-Th dates on these heads is deferred to Sections 1.3.1.10 and 1.3.1.12.

1.3.1.7. Overlap of BUN-3 and BUN-4

The U-Th dates on BUN-3 and BUN-4 are close enough, their errors are small enough, and the records on each head are long enough and similar enough, that the records must overlap. Starting with the diedown labeled "1483" in blue ("1486" in red) on both BUN-3 and BUN-4 (Figures S9–S10), both heads experienced additional diedowns 23, 26, 33, 43, and ~55 years later—and both heads experienced faster-than-average upward growth beginning 26–33 years later—strongly suggesting those portions of the two heads are coeval. If that is the case, however, BUN-4 must be missing 36.5 outer bands that are preserved on BUN-3. That so many bands are missing from BUN-4 is surprising, considering that the head appears to be in good condition with minimal erosion, but the similarities in BUN-3 and BUN-4 leave little room for other interpretations. If the two records beginning with the diedowns labeled "1483"/"1486" do not coincide perfectly, then not only would there be a remarkable coincidence in the intervals between the subsequent diedowns, but the two records would be mutually exclusive and no portion of BUN-3 could overlap with any portion of BUN-4—a proposition that is inconsistent with the U-Th dating results.

1.3.1.8. Original elevation of BUN-3

BUN-3, and all the other heads within tens of meters, were clearly tilted and had settled relative to one another. By carefully surveying the most well preserved concentric ring of BUN-3, we were able to restore the head's original horizontality, but its original elevation was still unknown. Assuming BUN-4 was in place and that the HLS following each diedown was the same on the two heads (to within a small error), we determined the original elevation of BUN-3 by comparing the "1483", "1509", "1516", and "1526" (blue) post-diedown HLS on the two heads. The calculated original elevation of BUN-3 is reflected in the time series on Figure S9b.

1.3.1.9. Overlap of BUN-3 and BUN-8

The weighted means of the U-Th dates from the respective heads indicate that the outer preserved band of BUN-8 dates to AD 1479 ± 13, whereas the first diedown on BUN-3 dates to 1460 ± 8 (Table S3; Figures S6a, S9a). Taken at face value, this suggests more than 20 years of overlap of the two records. The morphologies of the two heads, however, and their respective (corrected) elevations, do not permit nearly as much overlap. Indeed, the initial diedown on BUN-3, which appears to have been more than a 12-cm diedown (possibly due to a transient oceanographic lowering), and the rapid upward growth that followed that diedown (Figure S9b), are not compatible with any part of the BUN-8 record; at most, only the part of the BUN-3 record prior to the initial diedown can overlap with BUN-8. If we allow for as much overlap as is permitted, then the first diedown on BUN-3 (labeled "1472" in blue and "1475" in red, Figure S9a) must be at least 45 years after the diedown at the beginning of the band labeled "1422" in blue ("1425" in red) on BUN-8 (Figure S6a), but the number of years between the diedowns might be more, if any bands have been eroded off the end of BUN-8. As may now be evident, we assume there are 50 ± 5 years between those two diedowns.

1.3.1.10. Dating results (Scenario 1)

Out of all the fossil heads sampled at the BUN-A site, the ones that provide the best constraints on the timing of the inner diedown of the sombrero-shaped generation of microatolls are BUN-5, BUN-7, BUN-8, and (if it is valid to assume the initial diedown on BUN-3 occurred 5 ± 5 years after the outermost preserved band of BUN-8) BUN-3. Combining all the dates on each head, respectively, we calculate weighted-mean estimates for the date of the inner diedown. Assuming Scenario 1 (a single diedown), these weighted-mean estimates are late 1437 ± 23, early 1425 ± 11, late 1434 ± 13, and early 1410 ± 10, from BUN-5, BUN-7, BUN-8, and BUN-3, respectively (Table S4). These combine to yield an overall weighted average of AD 1422.3 ± 6.1 (early 1422). Counting 50 years forward from this date, the initial diedown on BUN-3 would have occurred in early 1472, and the best estimate for the outer preserved band of BUN-3 would be AD 1577. Figures S5a, S6a, S8a, S9a, and S10a show, in blue, the preferred banding dates for Scenario 1 (based on these calculations) for slabs BUN-7, BUN-8, BUN-5, BUN-3, and BUN-4, respectively. It is worth pointing out that, although the U-Th date on BUN-4 was not directly involved in these calculations, it is consistent with (within error of) the preferred dates for Scenario 1 (Figure S10a).

Figure S11a shows the composite 14th–16th century relative sea level history for BUN-A (Scenario 1), based on all the relevant heads at the site and on the above calculations. From this figure, it is evident how BUN-5 fills in the part of the BUN-7 record lost by erosion of its upper crown: although BUN-7 provides an excellent record of relative sea level from AD 1303 to 1404, BUN-5 provides the best record from 1405 until shortly before the 1422 uplift. It is also evident how BUN-3 and BUN-4 overlap, and how BUN-3 cannot overlap more with BUN-8. And although we have not yet discussed BUN-6 much, it appears as though BUN-6 must have settled, as it is necessarily lower than coeval heads.

In addition to the problem of settling, the exact age of BUN-6 is also problematic. Interpretation of the two dates from BUN-6 is not straightforward. The two dates are mutually exclusive, as they are only compatible when the error of each is simultaneously considered at 5σ (Table S3; Figure S7a). On Figures S7a, S7b, and S11a, we assign dates to BUN-6 by assuming the large diedown near the end of the BUN-6 record coincides with the initial diedown on BUN-3. This produces a result similar to that suggested by the weighted mean of the (mutually inconsistent) U-Th dates on the head. However, given the other problems of settling and severe erosion of this head, this head is in general not very useful, and we will not focus on it further.

Finally, we note that some question might exist as to the validity of basing the date of the inner diedown in any part on BUN-3. If we re-calculate a weighted-mean estimate for the date of the inner diedown of the sombrero-shaped heads based only on BUN-5, BUN-7, and BUN-8, while still assuming a single diedown (Scenario 1), the result is AD 1430.4 ± 7.9 (early 1430), roughly 8 years later.

1.3.1.11. 1422 uplift (Scenario 1)

To quantify the 1422 uplift, assuming there was only a single diedown (Scenario 1), we measure down from the HLG on BUN-5 in the years before 1422 to the post-diedown HLS in 1422 on BUN-8. We estimate that uplift to be 77 cm, as shown on Figure S11a. After the 1422 diedown, BUN-8 experienced unrestricted upward growth of at least 11 cm in ~11 years, suggesting the coseismic uplift was followed by a decimeter of postseismic subsidence.

1.3.1.12. Dating results (Scenario 2)

We now determine the timing of the inner diedown of the sombrero-shaped microatolls, assuming the dual diedown hypothesis (two closely timed diedowns ~8 years apart; Scenario 2) described in Section 1.3.1.3. As in Scenario 1, the slabs that provide the best constraints on the timing of the inner diedown are BUN-5, BUN-7, BUN-8, and (if it is valid to assume the initial diedown on BUN-3 occurred 5 ± 5 years after the outermost preserved band of BUN-8) BUN-3. Combining all the dates on each respective head, we calculate weighted-mean estimates for the date of the inner diedown. The estimates for the first (and larger) of the successive diedowns are still late 1437 ± 23 and early 1425 ± 11 from BUN-5 and BUN-7, but the appropriate dates from BUN-8 and BUN-3 are 8 ± 2 years earlier than in Scenario 1, or late 1426 ± 13 and early 1402 ± 10, respectively (Table S4); these combine to yield an overall weighted average of AD 1417.4 ± 6.2 (mid-1417). The second (smaller) diedown would have occurred 8 ± 2 years later. Counting 50 years forward from the date of the second diedown, the initial diedown on BUN-3 would have occurred in early 1475, and the best estimate for the outer preserved band of BUN-3 would be AD 1580. Figures S5a–S10a show, in red, the preferred Scenario 2 banding dates for slabs BUN-7, BUN-8, BUN-6, BUN-5, BUN-3, and BUN-4. Again, although the U-Th date on BUN-4 was not directly involved in these calculations, it is consistent with (within error of) the preferred dates for Scenario 2 (Figure S10a).

Figure S11b shows the composite 14th–16th century relative sea level history for BUN-A (Scenario 2), based on all the relevant heads at the site and on the above calculations. As we see by comparing Figures S11a and S11b, the main difference between the two scenarios is that, in Scenario 2, data prior to the inner diedown are shifted 5 years earlier, whereas data after the inner diedown are shifted 3 years later.

Finally, considering the questionable validity of basing the date of the inner diedown in any part on BUN-3, we again re-calculate a weighted-mean estimate based only on BUN-5, BUN-7, and BUN-8. For Scenario 2, the result is AD 1427.2 ± 8.0 (early 1427), roughly 10 years later than the estimate based on all four heads.

1.3.1.13. 1417 uplift (Scenario 2)

To quantify the 1417 uplift in Scenario 2, we once again measure down from the HLG on BUN-5 in the years before the inner diedown. This time, however, we assume the HLS immediately following the inner diedown was several centimeters above what remains of the "1417" (red) band on BUN-8 (Figure S6a); this is about 10–12 cm higher than the HLS following the second diedown (red "1425" on BUN-8). Thus, we estimate the inner diedown to be ~66 cm in Scenario 2 (Figure S11b), with a second diedown of ~11 cm, 8 years later. After that second diedown, BUN-8 experienced unrestricted upward growth of at least 11 cm in ~11 years.

While the first diedown is large and permanent and therefore must reflect uplift, the second diedown is not necessarily tectonic. In Scenario 2, we consider it equally plausible for (*a*) the first uplift to have been followed by a second uplift of ~11 cm and then ~11 cm of postseismic subsidence (perhaps a 2005-type event followed by a 2008-type event followed by subsidence), or (*b*) the first uplift to have been followed ~8 years later by a non-tectonic diedown caused by a strong positive IOD event similar to the one in 1997–98.

1.3.1.14. Interseismic submergence

The interseismic submergence rate at BUN-A has varied considerably over the seismic cycle and from one seismic cycle to the next, although it has also remained steady for decades at a time. From BUN-7 and BUN-5, we estimate the average interseismic submergence rate for the century before the large uplift (AD 1311–1422) to be 5.5 mm/yr (for simplicity, dates in this section will be according to Scenario 1). A close examination of BUN-7, however, reveals significant deviations from this average: after a period of faster submergence prior to 1311, it was a mere 2.2 mm/yr between 1311 and 1340, began accelerating some time between 1340 and 1345, and ultimately settled to 6.6 mm/yr from 1353 until perhaps 1422 (Figure S11a). We estimate the rate for 1433–1466 to be a much lower 0.3 mm/yr, based on BUN-8 (Figure S11a). The long-term (AD 1481–1576) average submergence rate recorded by BUN-3 is 6.0 mm/yr. The morphology of the head, however, implies that this rate was not constant over the entire century. The average rate was 5.8 mm/yr from 1481 to 1516, increased to 11.7 mm/yr from 1516 to at least 1527, was below the long-term average (but is poorly resolved) until ~1545, and then returned to 5.6 mm/yr from 1545 until at least 1576 (Figure S9b). Similarly, BUN-4 records an average rate of 5.9 mm/yr from 1480 to 1516, followed by an average rate of 10.1 mm/yr from 1516 until at least 1538 (Figure S10b). The faster submergence rate beginning around or just prior to 1516 probably reflects a period of faster interseismic tectonic subsidence, but we should not preclude an extended period (2–3 decades) of persistently higher-than-average sea level, as the early and late parts of the HLS record on BUN-3 are collinear. The cause of the exceptionally pronounced upward step in the morphology of the BUN-3 and BUN-4 microatolls was clearly not a sudden (effectively instantaneous) subsidence event; during the decades of rapid upward growth, both BUN-3 and BUN-4 repeatedly experienced HLS "hits," an indication that the corals' HLG was close to their theoretical HLS for most, if not all, of that time. If eustatic sea level change was negligible in the millennium preceding the 20th century AD, an issue that is not resolved (see discussion by *Meltzner et al.* [2010a]), this would imply that tectonic subsidence rates prior to the 20th century roughly equal the submergence rates determined from our fossil microatolls.

1.3.1.15. Maximum uplift at Bunon in 1394 and 1450

Two large uplift events that occurred on northern Simeulue in AD 1394 ± 2 and 1450 ± 3 [*Meltzner et al.*, 2010a] do not show up as significant events at Bunon, even if all reasonable uncertainties in the dating are taken into consideration. Based on the BUN-7 and BUN-5 records, the BUN-A site experienced fairly steady interseismic submergence of 6.6 mm/yr from 1353 possibly until 1422 in Scenario 1 (1348–1417 in Scenario 2), without any diedowns larger than

~5 cm within that period (Figures S5, S8, S11). Even if we instead use the inner diedown dates estimated without BUN-3 (Scenario 1: all dates would be shifted 8 years later, as discussed in Section 1.3.1.10; Scenario 2: all dates would be shifted 10 years later, as discussed in Section 1.3.1.12), and even if we allow for uncertainties of 6–8 years (as indicated in Table S4 and Sections 1.3.1.10 and 1.3.1.12), it is inescapable that no significant change occurred at BUN-A around the time of the 1394 uplift seen at multiple sites on northern Simeulue.

As for effects in AD 1450 at Bunon, the BUN-8 record shows that the BUN-A site experienced no diedowns larger than ~10 cm in the 44 years following the inner diedown of AD 1422 (Scenario 1) or following the ~11 cm diedown of AD 1425 (Scenario 2) (Figures S6, S11), although a ~10 cm diedown around 1450 on BUN-8 may correspond to the 1450 uplift on northern Simeulue. As before, even if we instead use the inner diedown dates estimated without BUN-3, and even if we allow for uncertainties of 6–8 years in the dates, it is inescapable that no sizable change occurred at BUN-A around the time of the 1450 uplift on northern Simeulue.

1.3.2. 9th–11th century record at BUN-A

In addition to the abundant fossil microatolls at the BUN-A site belonging to the 14th–16th century populations described above, a solitary 7-m diameter pancake-shaped microatoll exists at the site (BUN-9; Figures S1, S12). We cut four discontinuous slabs from this head: BUN-9A through the outer edge, BUN-9B through the outer ring, BUN-9C through the second ring, and BUN-9D in the center. The slabs appear in their relative positions in Figure S12f. The number of annual growth bands between each slab can be estimated based only on the average band thickness in the slabbed portions of the head and on the distance between the slabs. Nonetheless, U-Th analyses provide a precise estimate for the age of the head's outer preserved band (AD 1019.0 ± 13.7, or the beginning of 1019; Table S3, Figure S12a). Counting back an estimated 167 ± 25 bands between the outer preserved band on BUN-9A and the initial diedown on BUN-9D, we estimate the BUN-9 head's record begins in the mid-9th century AD (Figure S12d). Minor tilting of BUN-9 was corrected for, through a careful survey of the head's concentric rings.

Comparing the positions of BUN-9D and BUN-9C, the site appears to have submerged by up to ~10 cm in the 20–25 years following the head's initial diedown, but subsequently the site was fairly stable, submerging at only 0.5 mm/yr from around AD 875 until the head's death 145–150 years later (Figure S12e). More importantly, the BUN-9 head yielded no evidence for any large uplift or subsidence events over the course of its history. Furthermore, the fact that the growth unconformities associated with the diedowns in BUN-9B and BUN-9C are preserved indicates that only modest amounts of erosion have occurred: the head's low relief and nearly flat top are original characteristics associated with the head's growth and cannot be the result of planation.

The BUN-9 record spans the estimated AD 956 ± 16 date for the death of a population of fossil coral microatolls at the Ujung Salang site of northern Simeulue, inferred to be a still earlier northern Simeulue uplift event [*Meltzner et al.*, 2010a]. If this interpretation of a large 10th-century uplift on northern Simeulue is correct, the BUN-9 head is solid evidence that it—like those in 1394, 1450, and 2004—did not extend to the Bunon site.

1.4. Summary of Paleogeodetic Observations at Bunon

We have obtained three discrete histories of relative sea level at BUN-A, spanning the mid-9th to early 11th centuries AD, the early 14th to late 16th centuries, and AD 1982 to present. Figures S11c and S11d summarize observations of relative sea level at Bunon since ~AD 1300.

The mid-9th to early 11th century record is one of remarkably steady relative sea level, with no significant tectonic uplift or subsidence throughout the 170-year period preceding the BUN-9 microatoll's death. The death of BUN-9 around AD 1024 hints at a moderate or large uplift at that time, although the solitary microatoll conceivably could have died from another cause.

The record picks up again three centuries later around AD 1310 as the site was slowly accumulating strain, with a submergence rate of 2.2 mm/yr. Submergence accelerated around 1340 and remained at 6.6 mm/yr until the site rose suddenly around AD 1420, with 66–77 cm of coseismic uplift. This large uplift may have been followed by ~10 cm of postseismic subsidence. Then, from ~1435 to ~1470, there was little vertical change. The site began submerging again in the 1470s. The site continued to submerge at an average rate of 6.0 mm/yr from ~1480 until at least 1575, although it was as fast as ~11 mm/yr from ~1515 to ~1540; that faster submergence was followed by a short period of stability, by a few years of gradual emergence, or perhaps by a small uplift event of ~10 cm. The site resumed submerging at ~5.6 mm/yr from ~1545 until at least 1575. Shortly after 1575, the BUN-3 population of microatolls died, possibly due to coseismic uplift.

Finally, the modern record reveals an interseismic tectonic subsidence rate of 5.3 mm/yr from 1986 to 1995 (3.6 mm/yr averaged over 1986–2002), followed by ~20 cm of coseismic uplift in 2002, ~81 cm of coseismic uplift in 2005, and as much as 8 cm of coseismic uplift in 2008, but no appreciable vertical change in 2004. We infer from observations elsewhere on southern Simeulue [*Meltzner et al.*, 2009] that Bunon was uplifted during the 1861 southern Simeulue–Nias earthquake, but we have no evidence to either confirm or refute this at Bunon.

Section S2. Results from the Pulau Penyu (PPY) Site

Pulau Penyu (literally, "Turtle Island") is a tiny islet 3 km off the northern northeast coast of Simeulue (Figure S13). At extreme low tide, when the post-uplift reef is exposed, the islet measures roughly 600 m by 300 m, but at high tide it is only 400 m by 200 m. Although Pulau Penyu is closer to the northern Simeulue locus of uplift, which was associated with the 2004 earthquake, the majority (if not all) of the uplift at Pulau Penyu occurred in 2005. In all, the 2004–2005 uplift at Pulau Penyu totaled only 36–38 cm. Thus, like Bunon, Pulau Penyu mostly acted as part of the southern Simeulue patch for the 2004–2005 sequence and was largely independent of the 2004 patch. In addition, Pulau Penyu rose during both the 2002 and 2008 earthquakes: ~10 cm in the 2002 earthquake, which had a locus of deformation centered ~25 km to the south-southeast, and ~11 cm in 2008, which was centered ~20 km to the south-southwest.

The Pulau Penyu site, PPY-A, occupies the northern and eastern sides of this islet (Figure S13). There are abundant modern heads and at least two generations of fossil microatolls that span the 15th–16th centuries AD. A total of one modern and three fossil coral microatolls—all of the genus *Porites*—were sampled from the PPY-A site (Table S1).

The oldest microatoll sampled at PPY-A overlaps with a large inferred uplift on the 2004 patch of northern Simeulue in AD 1450 ± 3 [*Meltzner et al.*, 2010a], allowing us to compare the behavior of the 2004 patch with that of the PPY-A site during an earlier rupture. As we have just demonstrated at Bunon, a comparison of the Pulau Penyu and 2004-patch records reveals strikingly disparate relative sea level histories around AD 1450; neither the 2004 event nor the 1450 event had a significant effect at Pulau Penyu. The similarity of the abrupt southeastward rupture terminations in the two events suggests this behavior is persistent.

2.1. Vertical Changes since 2004 at Pulau Penyu

2.1.1. Coseismic uplift in 2004–2005

Although Pulau Penyu was not visited by our field team until July 2007, K. Sieh flew along the northern northeast coast of Simeulue by helicopter in mid-January 2005. At a site 3 km to the west-southwest of PPY-A, he observed microatolls that had died down an estimated 20 cm due to recent uplift. Adjusting that estimate for the fact that ELW got 13 cm lower in the year preceding the 2004 earthquake than it did during the brief period between the uplift and the mid-January observation, we estimate ~33 cm of uplift in 2004 at his observation site. The site of this mid-January observation is directly up-contour of PPY-A, essentially in a direct line between PPY-A and the region of maximum uplift in 2004 on Simeulue; for this reason alone, we would expect that the uplift in 2004 at PPY-A was considerably less than 33 cm—perhaps 15 cm or less.

The coral microatolls at PPY-A are helpful but do not provide a clear answer to the question of uplift in 2004. By the time we first visited the site in July 2007, any subtle evidence that might have existed of discrete diedowns in 2004 and 2005 had been destroyed or rendered equivocal by erosion. From the slabbed modern microatoll cross-section (PPY-1; Figure S14a), and from careful observations and surveys of a number of other modern microatolls at the site, it is apparent that all the heads at the site experienced a significant diedown (> 5 cm) in late 1997, a diedown of up to 5 cm in late 2003 or early 2004, and a much larger diedown in early 2005. A few microatolls at the site, not including PPY-1, experienced an additional diedown of their uppermost few millimeters around late 2002. Additionally, several of the modern microatolls exhibit irregular subtle "bumps" on their outer surfaces that could be interpreted as an additional diedown in the months before the 2005 diedown; however, the elevations of these bumps are not consistent from one head to another (with a range of 15 cm) where they are present, and they are not seen on about half of the heads. There is no bump suggestive of a late 2004 diedown on the slab of PPY-1, but there appears to be a few millimeters of erosion of the slab's outer surface; it is not clear whether a subtle outer lip resulting from a late 2004 diedown would still have been discernable in 2007 when we visited the site and slabbed the head. The beginning of a 2005 band is visible on the slab, but only near its base. Either there was a few millimeters more erosion of the upper part of the outer surface of PPY-1 than of its lower part, or there was a diedown at the end of 2004 of as much as 16 cm, followed 3 months later by the 2005 diedown that killed the head entirely, which was then followed by sufficient erosion (a few millimeters) to destroy evidence of the outer lip that would have formed in the 3 months between the two diedowns. Hence, all evidence considered, we cannot say whether any diedown occurred as a result of the 2004 earthquake, but if one did, it was at most 16 cm. Considering that ELW got 2 cm lower during the brief period between the 2004 and 2005 earthquakes than it did in the year preceding the 2004 earthquake, this suggests the 2004 uplift, if there was any, was no more than 14 cm.

In July 2007, we measured the uplift at site PPY-A using the same two methods as at BUN-A. By measuring the difference between water level and pre-uplift HLG and tying the water level to ELW, we determined the net uplift between late 2004 and July 2007 at PPY-A to be 36 ± 8 cm. At the same time, by comparing the pre-uplift HLG with the post-uplift HLS, we determined the 2004–2005 diedown to be 39 ± 6 cm; correcting that value for the fact that ELW during the period between the March 2005 earthquake and the July 2007 measurement was 1 cm lower than during the year preceding the 2004 earthquake yields a net uplift estimate of 38 cm, essentially identical to the first measurement. Thus, uplift at Pulau Penyu totaled 36–38 cm in 2004–2005, with at most 14 cm of that occurring in 2004.

2.1.2. Coseismic uplift in 2008

In February 2009, nearly a year after the 2008 Simeulue earthquake, we returned to the PPY-A site and observed consistent 1–3 cm fresh diedowns on all of the microatolls that were still alive. These diedowns appeared to be no more than 1 year old, and necessarily had occurred after our site visit in 2007; we attribute them to uplift in February 2008. Correcting for the fact that ELW during the period between the February 2008 earthquake and the February 2009 observations was 9 cm higher at Pulau Penyu than during the year preceding the 2008 earthquake, this implies ~11 cm of uplift at PPY-A in 2008.

2.2. Modern Paleogeodetic Record at Pulau Penyu

One modern microatoll was slabbed at the PPY-A site: PPY-1 (Figure S14a). As usual, we followed the methodology for slab extraction and analysis described by *Meltzner et al.* [2010a]. As it turns out, this head has a record extending further back than any other modern microatoll we have yet found on or near Simeulue.

2.2.1. Diedowns and causes

PPY-1 began growing around AD 1920 and first recorded an HLS "hit" around 1928. The head recorded additional HLS diedowns in approximately 1935, 1938, late 1942, late 1943, 1950, late 1955, and late 1961, although counting uncertainties in the early 1960s and earlier mean that these dates could all be in error by 1 or 2 years. After 1961, the diedowns that were recorded and preserved on PPY-1 date to 1989, late 1997, late 2003 or early 2004, possibly late 2004, and ultimately early 2005, when the coral died completely. As mentioned earlier, other heads at the site experienced a slight diedown around late 2002.

We focus on the diedown history since 1961, because this most recent part of its history is comparable with the histories of heads that we sampled at numerous sites elsewhere on Simeulue [*Meltzner et al.*, 2010a]. As with heads at other sites on Simeulue, the late 2004 and early 2005 diedowns are associated with the two great megathrust earthquakes; diedowns in the year and a half after late 2002 are both attributed to uplift in late 2002; and the late 1997 diedown

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was ubiquitous and contemporaneous with the 1997–98 strong positive IOD event. No diedown in 1989 is evident at sites on northern Simeulue, but small diedowns occurred at the other central Simeulue site, Bunon. Collectively, the diedowns at Pulau Penyu and Bunon weakly hint at an aseismic event under central Simeulue in 1988 and/or 1989.

2.2.2. Coseismic uplift in 2002

Although PPY-1 did not experience a “hit” in late 2002, a few other microatolls at the site—which were growing barely higher than PPY-1 at the time—experienced a diedown of their uppermost few millimeters in late 2002, around the time of the 2002 Simeulue earthquake. From these heads, we determined that the post-2002 HLS was 3 cm higher than the post-1997 HLS at PPY-A. Considering that ELW in the months following the November 2002 earthquake was 13 cm higher than during the 1997–98 IOD yields an estimate of ~10 cm net uplift between the end of 1997 and the end of 2002 at PPY-A. We attribute this uplift to the 2002 earthquake.

About a year after the late 2002 diedown, in late 2003 or early 2004, all the heads at Pulau Penyu experienced a diedown of up to 5 cm, reaching levels ~5 cm lower than the post-2002 HLS. Given that ELW in early 2004 reached 7 cm lower than it had in the six months following the November 2002 earthquake, this diedown is about what we would expect as a delayed result of the ~10 cm coseismic uplift in 2002, with little change (perhaps ~2 cm of postseismic subsidence) in the following year.

2.2.3. Interseismic subsidence

Figure S14 consists of both a cross-section and an HLG and HLS time series of PPY-1. Together these provide important information on subsidence rates and history for the PPY-A site. Following the methodology of *Meltzner et al.* [2010a], we attempt linear least squares fits to the data, using the head’s HLG in the years prior to each diedown, but omitting data prior to the head’s initial diedown or following the 2002 uplift. (Furthermore, we treat any rates based in any part on 1998–2002 data with caution, because it is not clear whether heads had grown up to near their theoretical HLS following the 1997 diedown but prior to the 2002 uplift.)

A quick glance at the data suggests that there was a marked change in the submergence rate around 1980; for this reason, we attempt separate regressions for the rates prior to and after 1980. The linear least squares fits for PPY-1 suggest fairly steady interseismic submergence at 5.9 mm/yr over the period 1932–1980 and slower submergence of 1.7 mm/yr from 1980 through at least 1995. If we assume eustatic sea level rose uniformly by 2 mm/yr over the entire period 1932–1995, these submergence rates would correspond to tectonic subsidence at 3.9 mm/yr over

1932–1980, followed by 0.3 mm/yr of uplift over 1980–1995. However, as discussed by *Meltzner et al.* [2010a], *Jevrejeva et al.* [2006] calculate that Indian Ocean sea levels, on average, were rising by ~4 mm/yr from ~1930 to ~1947, by ~3 mm/yr until ~1958, by ~2 mm/yr until ~1965, by ~1 mm/yr until ~1980, and by < 0.5 mm/yr since 1980. If these rates of sea level rise are appropriate for Simeulue, they suggest that PPY-A experienced tectonic subsidence of 3–4 mm/yr averaged over 1932–1980, and a little more than 1 mm/yr of tectonic subsidence between 1980 and 1995.

2.3. Fossil Paleogeodetic Record at Pulau Penyu

We slabbed three fossil microatolls at PPY-A. PPY-4 (Figure S15) was the best preserved of a small population of microatolls with similar morphologies, all at the same elevation. It experienced a diedown early in its life but then grew upward for 15–30 years before experiencing another "hit." It grew for more than 53 years after the initial diedown. PPY-3 (Figure S16) was at the same elevation as PPY-4 but was eroding out of the beach and had a unique morphology; no other microatolls like it were found. Upon slabbing PPY-3, we discovered that the inner part of this head was overturned on two separate occasions. PPY-2 (Figure S17) was ~10 cm higher than the other slabbed fossil microatolls (Table S3). It was also the best preserved of a small population of microatolls with similar morphologies, all at the same elevation. Like PPY-4, PPY-2 experienced a diedown fairly early in its life, but unlike on PPY-4, this initial diedown was followed quickly by a second and then by low rates of long-term submergence. We dated one sample each from PPY-2, PPY-3, and PPY-4 by U-Th analysis (Tables S2–S3).

2.3.1. Dating results, slab analysis, and interpretation

The dating results indicate that PPY-4 and PPY-3, which were at the same elevation but had different morphologies, were coeval: both died around AD 1490 (Figures S15–S16). Although we had thought in the field that they were from different generations, analysis of the two slabs reveals that their growth histories are compatible with one another. PPY-3's unique morphology, it turns out, results from having been overturned twice during its growth history, ~9 years apart. PPY-3 is also tilted and might have settled by a few centimeters since it was alive. We were able to restore the original horizontality of the head with a careful survey of its outer ring, and we restored its original elevation by comparing the estimated 1476 post-diedown HLS (date labeled in blue) on PPY-3 and PPY-4, assuming the latter was in place.

PPY-2 is slightly higher and about 8 decades younger than PPY-3 and PPY-4. The U-Th analysis suggests it died in the 1560s (Figure S17). The head's record extends back nearly 90 years from its outer preserved band, suggesting that the earliest part of PPY-2 could be old enough to overlap with PPY-3 and PPY-4; if the U-Th dates are taken at face value, all three heads would overlap by nearly 20 years. We note, however, a potential problem with this straightforward interpretation: PPY-2 did not gain much elevation over its growth history, and HLS over the course of the head's life was never lower than 20 cm below the head's outer rim. Equivalently, this is 10 cm lower than the outer rim of PPY-4.

The main issue is that any diedown in which the HLS was low enough to kill PPY-3 and PPY-4 entirely would have been ~24 cm lower than the outer rim of PPY-4 and ~34 cm lower than the outer rim of PPY-2. This would have also killed PPY-2 entirely, or at least 15 cm lower than any of the observed diedowns. Alternatively, perhaps there was a diedown during which PPY-3 and PPY-4 both died to a lower elevation than the site HLS at the time. For instance, even if the lower parts of PPY-3 and PPY-4 were below the HLS at ELW, the shallow water around those corals may have gotten so warm that those heads died; if the water was just a little deeper or the circulation at ELW just a little better in the vicinity of PPY-2, it might have died down only to the HLS at the time.

If we assume the initial diedown on PPY-2 coincides with the death of PPY-3 and PPY-4, the three heads would overlap by ~11 years. This scenario (Scenario A on Figures S15–S18) is more consistent with the U-Th dating results but would require that PPY-3 and PPY-4 died 15 cm lower than HLS on PPY-2. If we instead assume that no part of PPY-2 overlaps with PPY-3 or PPY-4 and that PPY-2 started growing almost immediately after the death of PPY-3 and PPY-4 (Scenario B on Figures S15–S18), the three U-Th dates can no longer all be correct, but this is more consistent with the heads' elevations and morphologies. Still, even in Scenario B, if PPY-3 and PPY-4 were killed by tectonic uplift, the HLS could not have risen sufficiently to allow PPY-2 to grow unless the uplift was followed immediately by a substantial amount of postseismic subsidence.

The primary differences in the implications of Scenarios A and B lie in the amount of the inferred uplift at the time of the death of PPY-3 and PPY-4, and in its timing. (In that regard, this is analogous to the differences in Scenarios 1 and 2 at Bunon, which are unrelated to Scenarios A and B at Pulau Penyu.) We estimate the timing of the diedown based on a weighted average of the U-Th dates from all three heads at PPY-A, in the manner shown in Table S4. Specifically, in order to use the U-Th date from PPY-2 in the calculation, we need to make an assumption about when this diedown occurred relative to the life of the PPY-2 head. For Scenario A, we assume the diedown occurred 77 years prior to the outer preserved band on PPY-2, whereas for Scenario B, we assume the diedown occurred 88 years prior to the outer preserved band. The resulting weighted mean estimates for the diedown are AD 1488.1 ± 3.2 (early 1488) for Scenario A, and AD 1486.1 ± 3.6 (early 1486) for Scenario B. Counting the appropriate numbers of years forward from these respective dates, the best estimates for the outer preserved band of PPY-2 would be AD 1564 in Scenario A and AD 1573 in Scenario B. The preferred banding dates for each scenario are shown in blue and red, respectively, on Figures S15–S17. Figure S18 shows the composite 15th–16th century relative sea level histories for PPY-A for both scenarios.

2.3.2. 1488 uplift (Scenario A)

To quantify the 1488 uplift, assuming the initial diedown on PPY-2 coincided with the death of PPY-3 and PPY-4 (Scenario A), we measure down from the HLG on PPY-3 and PPY-4 in the years before 1488 to the post-diedown HLS in 1488 on PPY-2. We estimate that uplift to be 10–11 cm, as shown on Figure S18a. In this scenario, it is unclear why PPY-3 and PPY-4 died entirely, but we assume that the cause is not an important part of the site's relative sea level history.

2.3.3. 1486 uplift (Scenario B)

Quantifying the 1486 uplift in Scenario B requires further assumptions. If we assume the uplift was sufficient to kill PPY-3 and PPY-4 entirely, then, based on the height of the part of the heads that would have been alive at the time, this amount is 24 cm at a minimum (Figures S15a, S16a, S18b). However, in order for the HLS to rise sufficiently to allow PPY-2 to begin growing, the 24 cm of coseismic uplift would have needed to be followed almost immediately by ~14 cm of postseismic subsidence. If, on the other hand, we are willing to invoke a near-coincidence between an uplift event and an unrelated transient oceanographic lowering in order to explain the death of PPY-3 and PPY-4, then an alternative explanation is that a smaller diedown (perhaps only ~12 cm) was followed almost immediately by a strong positive IOD event that caused the corals to die down ~12 cm further. Once the IOD event was over, the HLS would have been high enough for PPY-2 to begin growing.

2.3.4. Constraints at Pulau Penyu during the ~1420 Bunon uplift

Although PPY-4 may have started growing by the time of the ~1420 uplift at Bunon, nothing can be said about what happened at Pulau Penyu at the time. Even if the initial diedown on PPY-4 in ~1430 coincided with the "inner diedown" at Bunon (which is unlikely, given the small errors on the dates), nothing helpful can be said about the size of the initial diedown on PPY-4, because the head's elevation relative to HLS prior to its initial diedown is unknown.

2.3.5. Constraints at Pulau Penyu during the 1450 northern Simeulue uplift

In contrast to the situation with the 1420 event, PPY-4 does preclude a substantial diedown (> 15 cm) at Pulau Penyu around the time of the large northern Simeulue uplift in AD 1450 ± 3. First, there is no direct evidence for any diedown on PPY-4 around 1450. Second, the most closely dated diedown that has been inferred on the PPY-4 head occurred roughly 8–10 years later, in 1460 (Scenario A) or 1458 (Scenario B). Even if this is the AD 1450 northern Simeulue diedown, it could not have exceeded 10–15 cm at PPY-A, based on this head's morphology. And third, although the upper surface of PPY-4 has sustained considerable erosion and additional diedowns might have occurred that cannot be recognized, any unrecognized diedown around AD 1450 (assuming the bands are dated correctly, within 2σ) could not have exceeded 5–10 cm. Given the morphology of PPY-4, the only way an uplift exceeding 15 cm in ~1450 is possible is if the subsidence following the ~1430 diedown on PPY-4 exceeded 26 cm by a similar amount. Hence, there is no direct evidence for a diedown at Pulau Penyu around 1450, and the largest uplift around that time that can be readily explained is ~15 cm.

2.3.6. Interseismic submergence

As at Bunon, the interseismic submergence rate at Pulau Penyu has exhibited considerable variation, although it has also remained steady for decades at a time. Following the initial diedown on PPY-4 in AD 1432 (dates in this section will be according to Scenario A), PPY-4 grew upward 26 cm in 16 years, suggesting the 1432 diedown was followed either by a subsidence event or by a period of rapid interseismic submergence. It is worth noting that both the 1432 diedown and the subsequent submergence on PPY-4 occurred at about the same time as a minor uplift event on northern Simeulue [*Meltzner et al.*, 2010a]; either may be related to the northern Simeulue uplift. Submergence at Pulau Penyu slowed by the 1450s and continued at an average rate of 1.6 mm/yr until the uplift in 1488 (Figure S18a). Following the 1488 uplift, the site submerged at an average rate of 1.2 mm/yr until ~1537, based on the record of PPY-2. Submergence may have been faster than this average in the first decade after 1488, with the site experiencing almost no change from ~1500 until ~1537. Following 1537, the site submerged at an average rate of 5.6 mm/yr until at least 1560.

2.4. Summary of Paleogeodetic Observations at Pulau Penyu

We have obtained two discrete continuous histories of relative sea level at the PPY-A site, spanning the 15th–16th centuries and AD 1928 to present. Figure S18 gives summaries of observations and potential inferences of relative sea level at Pulau Penyu during the earlier period, and Figure S14b summarizes the observations from the modern period.

The Pulau Penyu record begins around AD 1430 with the initial diedown of PPY-4. This was followed by ~26 cm of submergence, which may have occurred either suddenly (for example, during an earthquake) or over as much as a decade. Starting in the 1450s, the site was submerging at 1.6 mm/yr, until sudden uplift of 10–24 cm around AD 1488. This event may have been followed by ~14 cm of postseismic subsidence. The site submerged at an average rate of 1.2 mm/yr from shortly after 1488 until the late 1530s or the 1540s. Submergence occurred at a faster clip of 5.6 mm/yr for the next two decades or so, until at least the 1560s. In the 1560s or 1570s, the PPY-2 population of microatolls died, possibly due to coseismic uplift.

The modern record indicates the site submerged steadily at 5.9 mm/yr from 1932 to 1980, but the submergence slowed to 1.7 mm/yr from 1980 through at least 1995. If a uniform eustatic sea level rise of 2 mm/yr is assumed since 1932, these submergence rates would imply tectonic subsidence of 3.9 mm/yr over 1932–1980, followed by 0.3 mm/yr of uplift over 1980–1995. However, time-dependent rates of sea level rise in the Indian Ocean over the 20th century modeled by *Jevrejeva et al.* [2006], if valid for Simeulue, suggest that PPY-A experienced tectonic subsidence of roughly 3–4 mm/yr from 1932 to 1980, and a little more than 1 mm/yr of tectonic subsidence between 1980 and 1995. This was followed by ~10 cm of coseismic uplift in 2002, 36–38 cm of uplift in 2004–2005 (with no more than 14 cm of that occurring in 2004), and ~11 cm of coseismic uplift in 2008.

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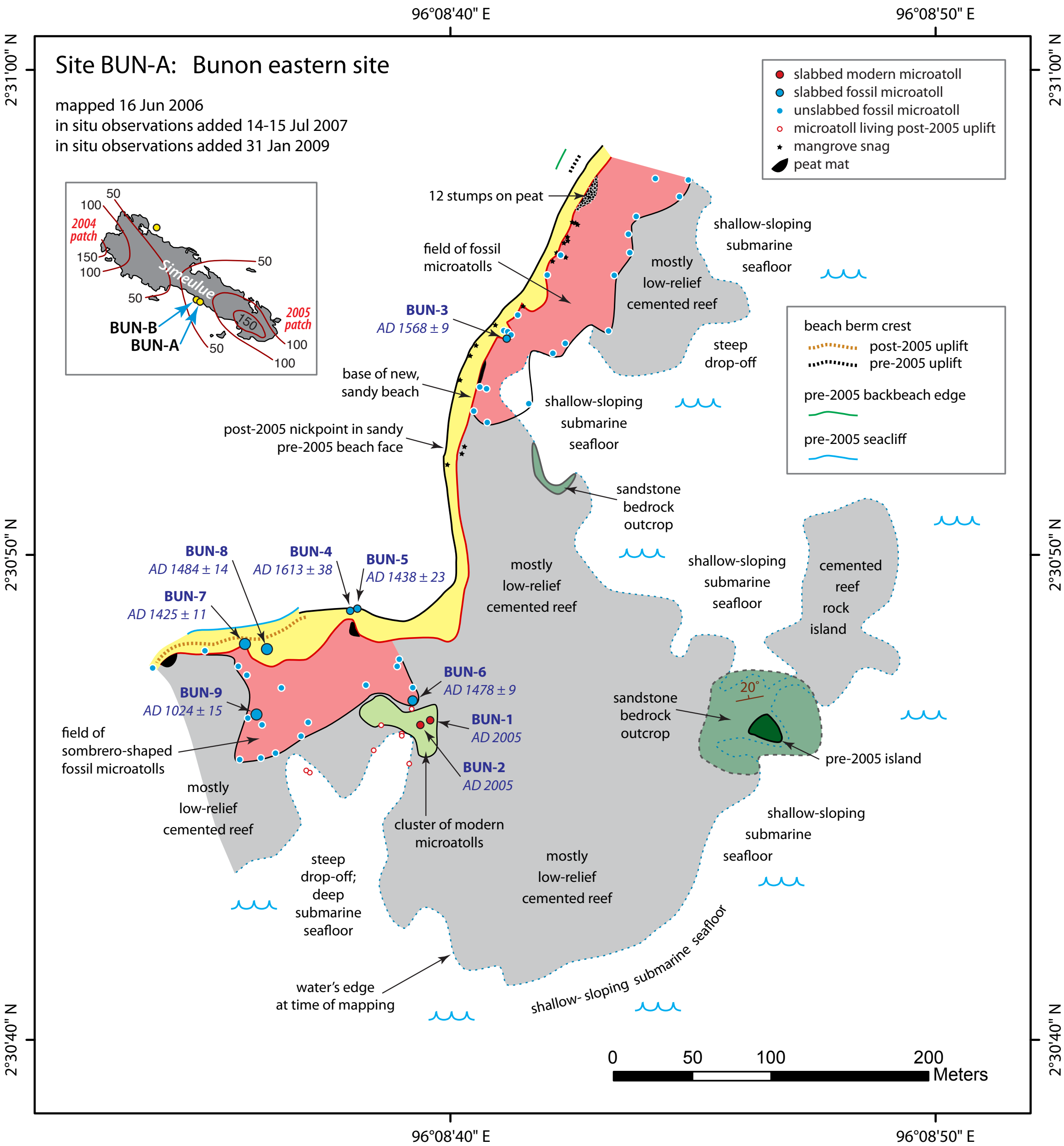

Figure S1. Map of site BUN-A, southwest coast of Simeulue, showing sampled microatolls and their dates of death. Inset shows the relative locations of the BUN sites on Simeulue, along with contours of cumulative uplift (in centimeters) in 2004 and 2005, modified from *Briggs et al.* [2006]. The locus of uplift on the northwestern part of the island is attributed to the 2004 earthquake, whereas the southeastern locus of uplift occurred in 2005.

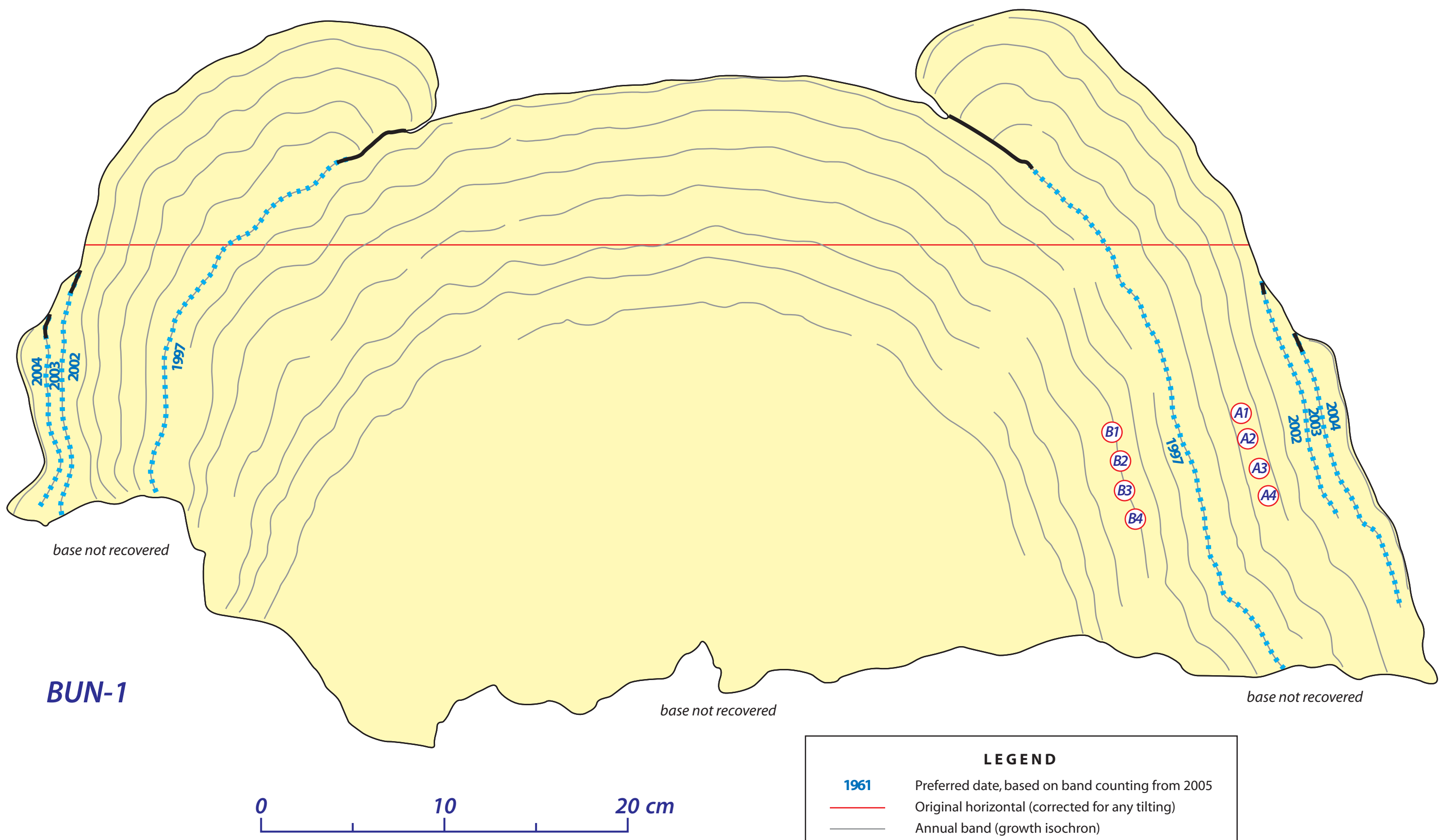

Figure S2a. Cross-section of slab BUN-1, from site BUN-A.

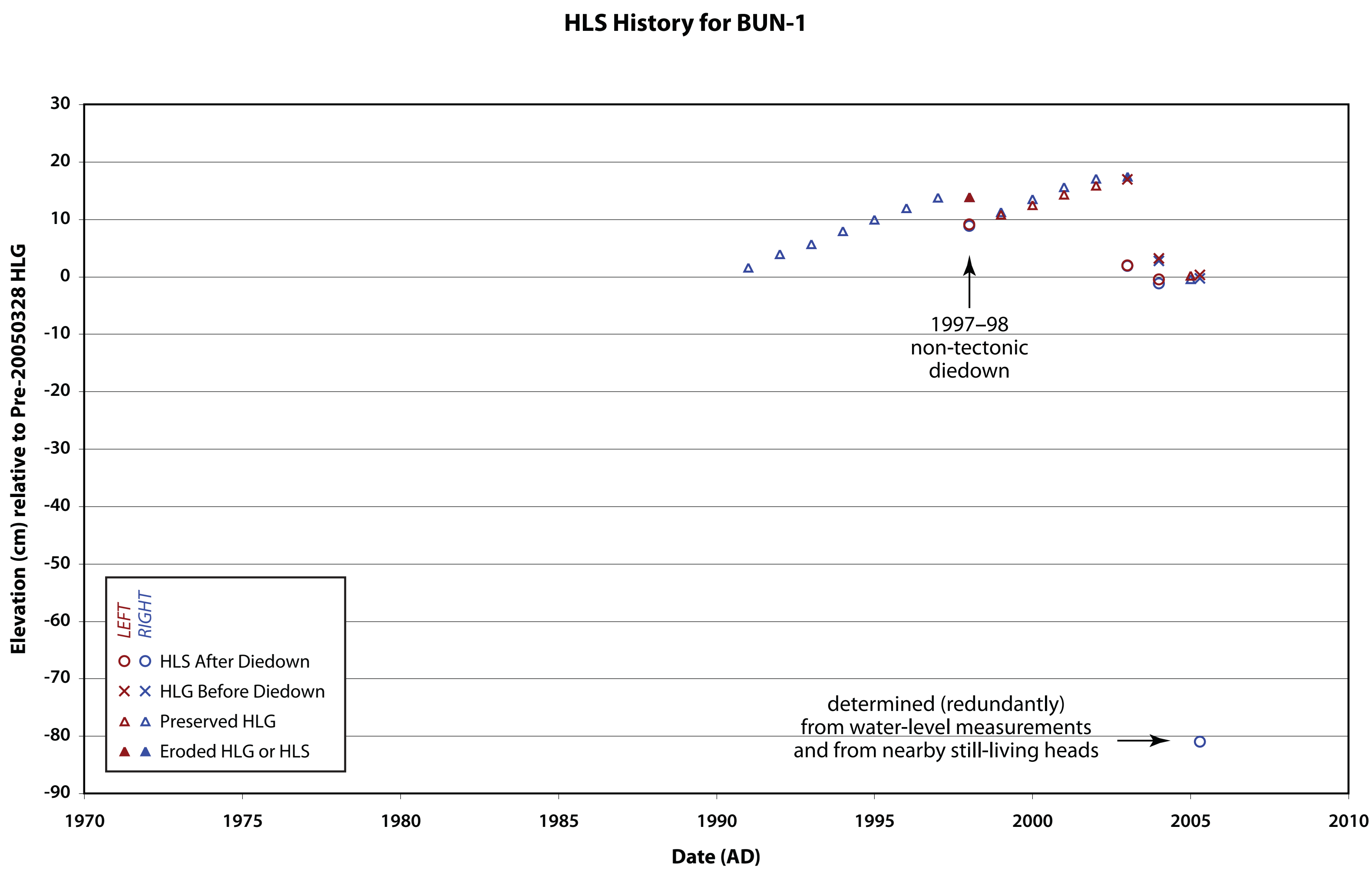

Figure S2b. Relative sea level history derived from slab BUN-1.

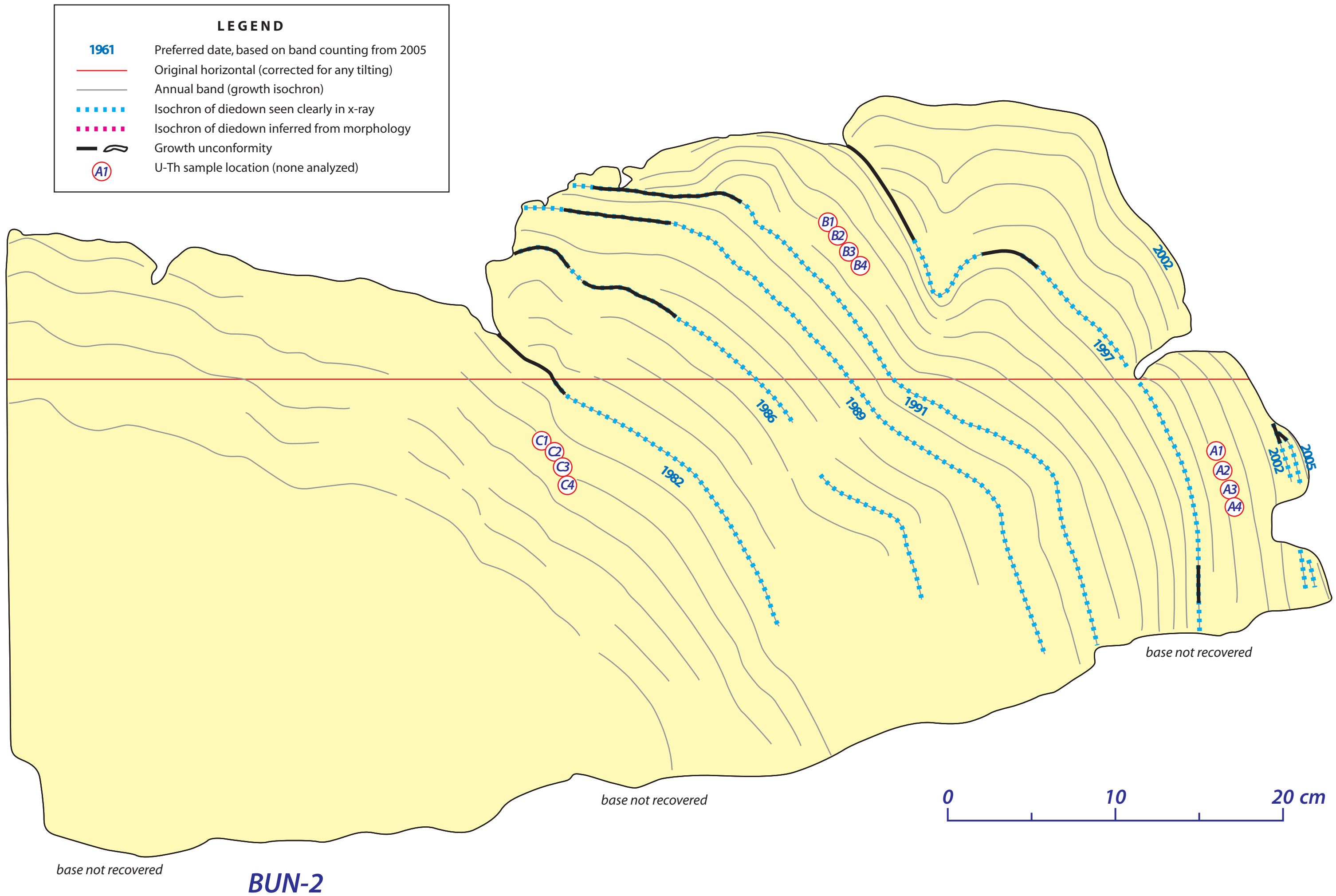

Figure S3a. Cross-section of slab BUN-2, from site BUN-A.

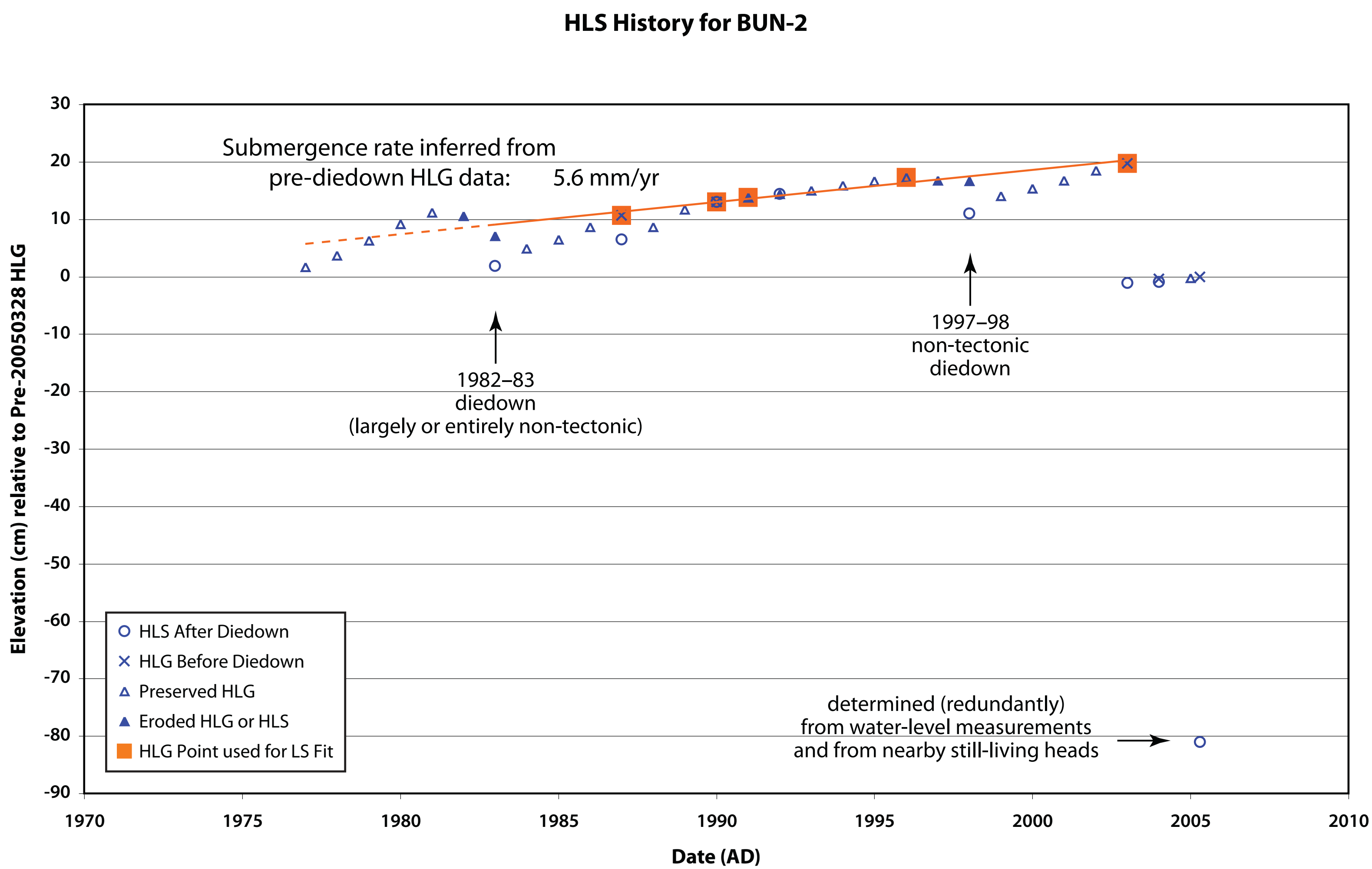

Figure S3b. Relative sea level history derived from slab BUN-2.

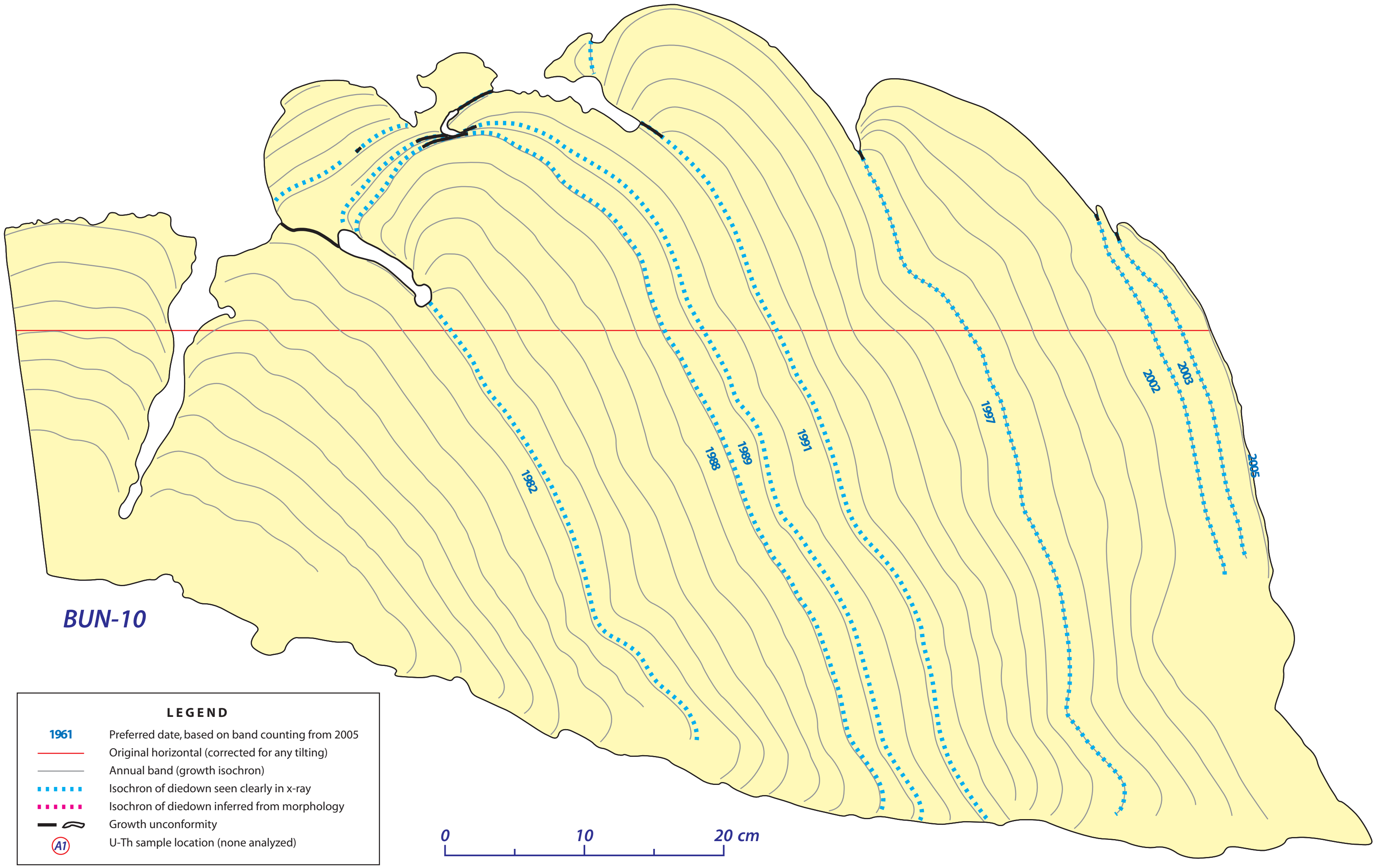

Figure S4a. Cross-section of slab BUN-10, from site BUN-B.

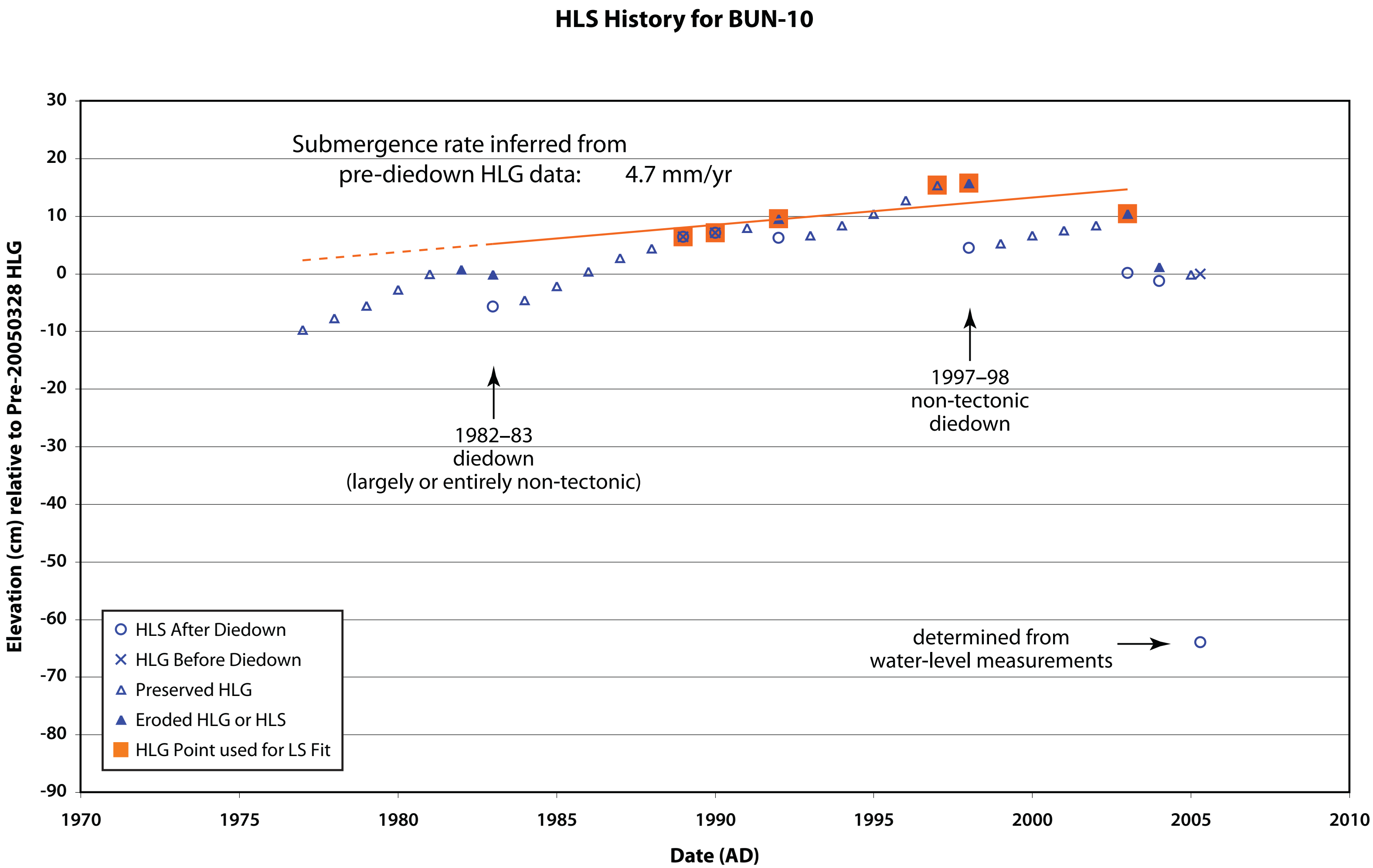

Figure S4b. Relative sea level history derived from slab BUN-10.

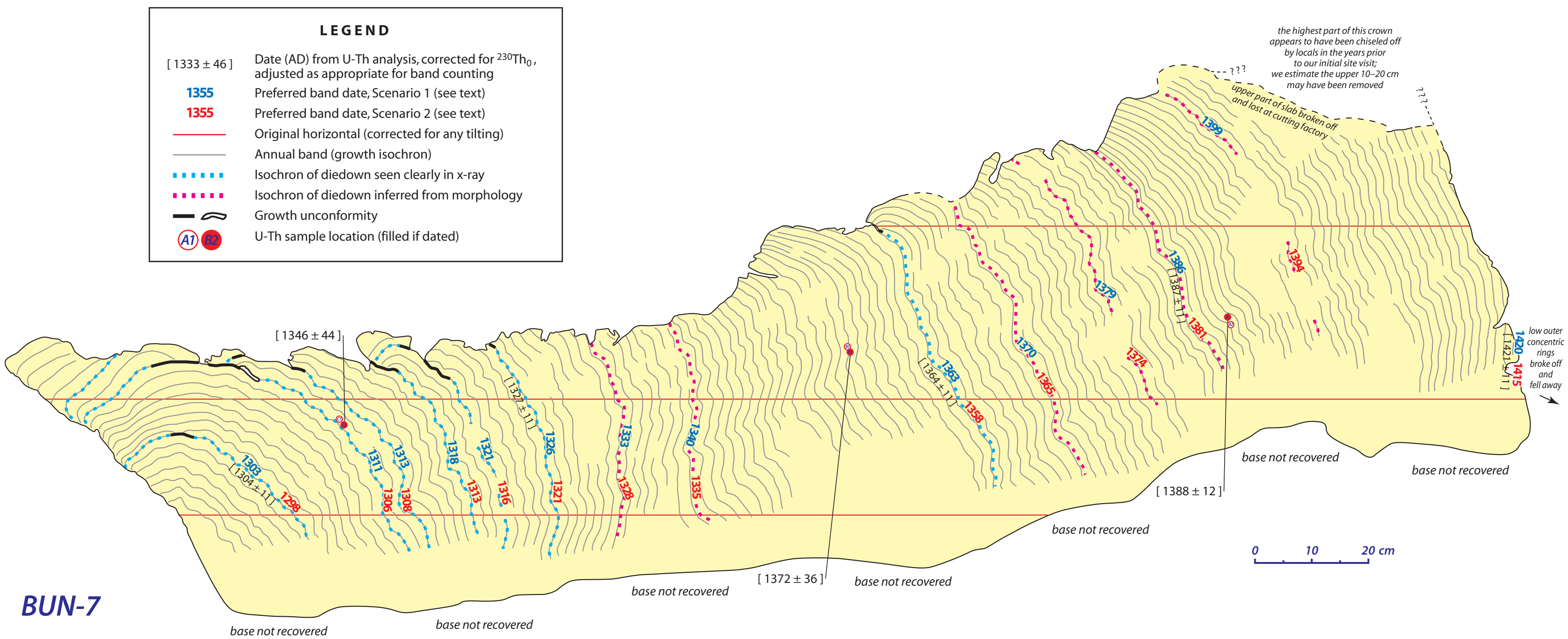

Figure S5a. Cross-section of slab BUN-7, from site BUN-A.

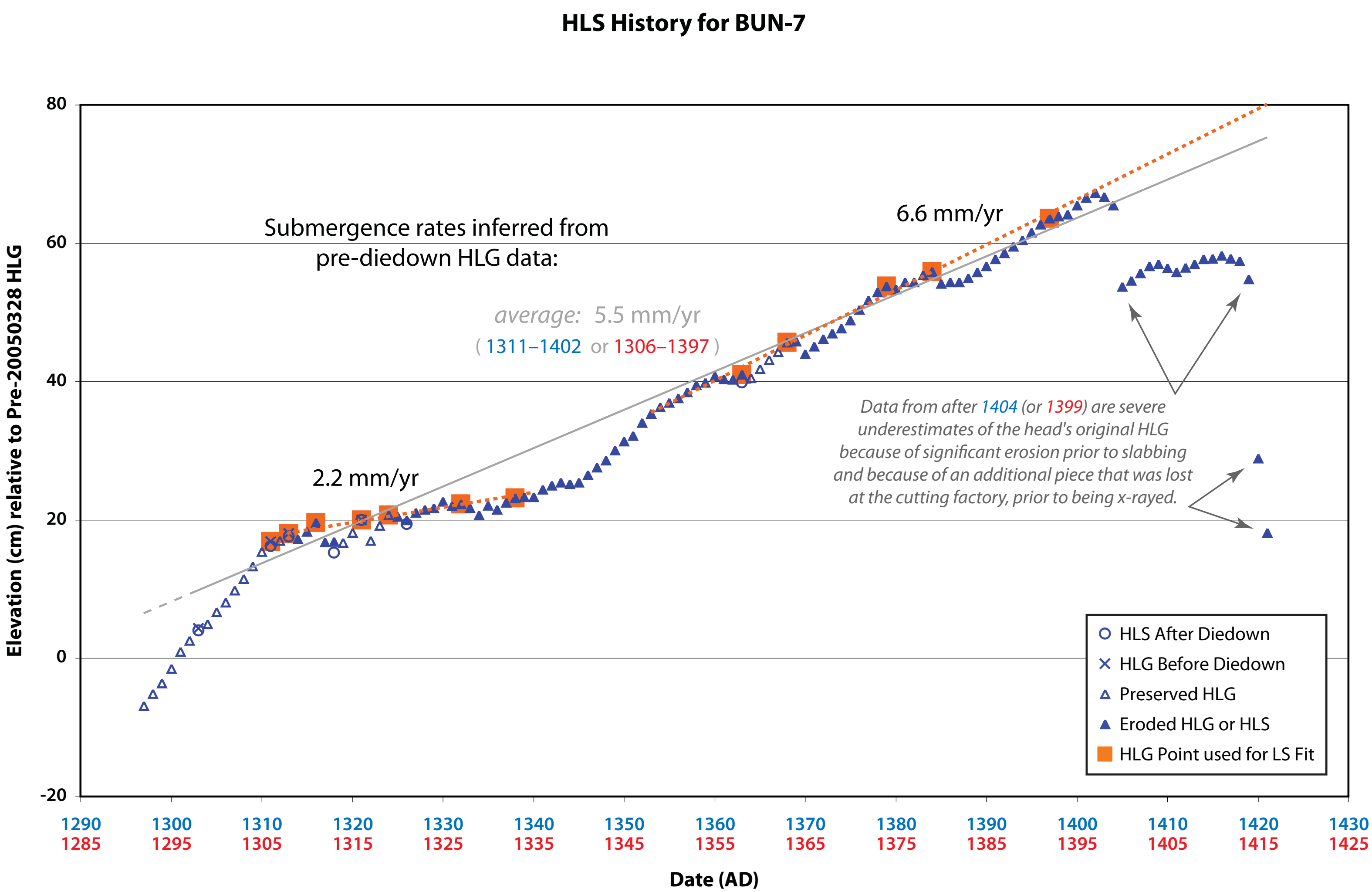

Figure S5b. Relative sea level history derived from slab BUN-7.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

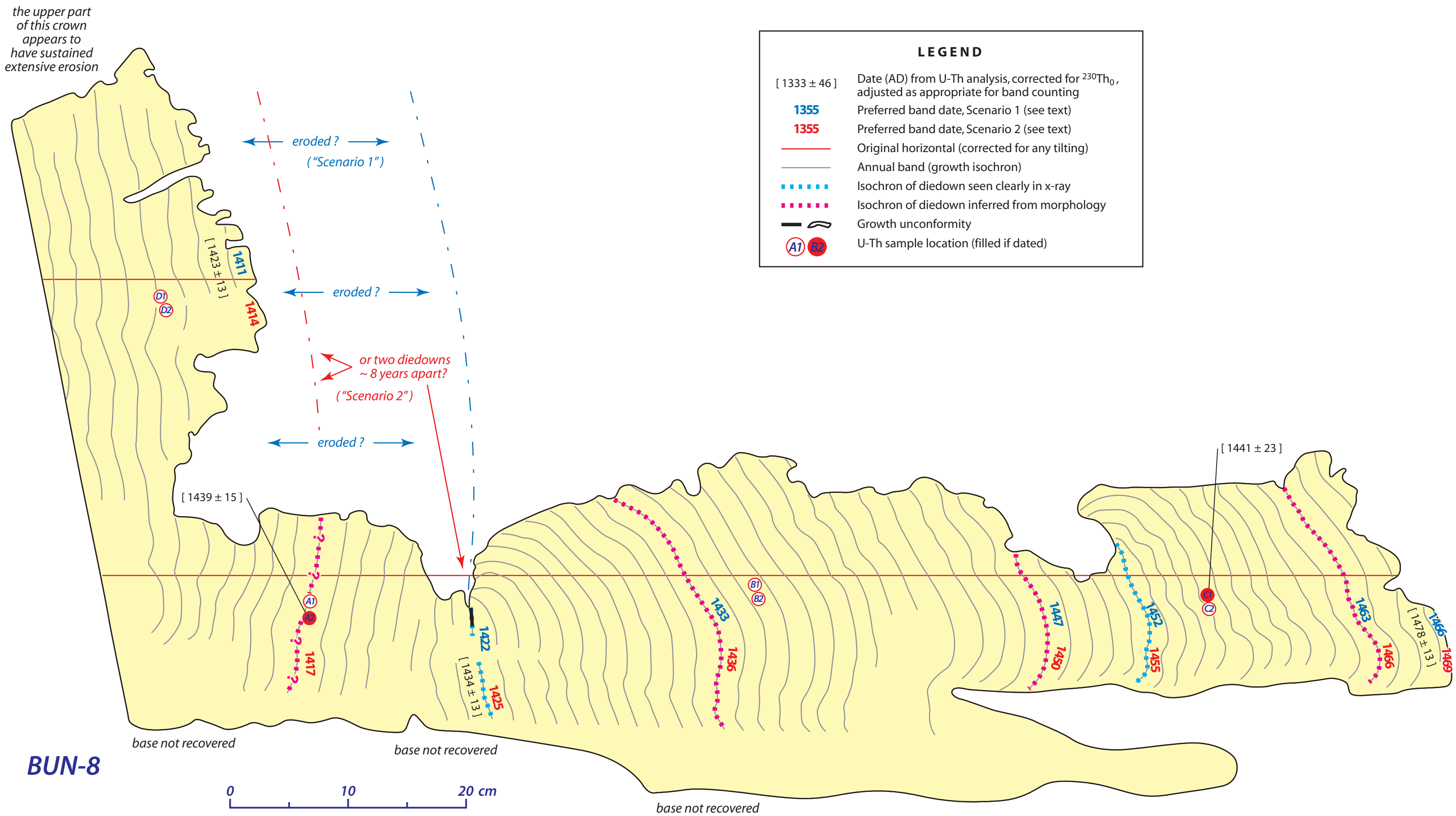

Figure S6a. Cross-section of slab BUN-8, from site BUN-A.

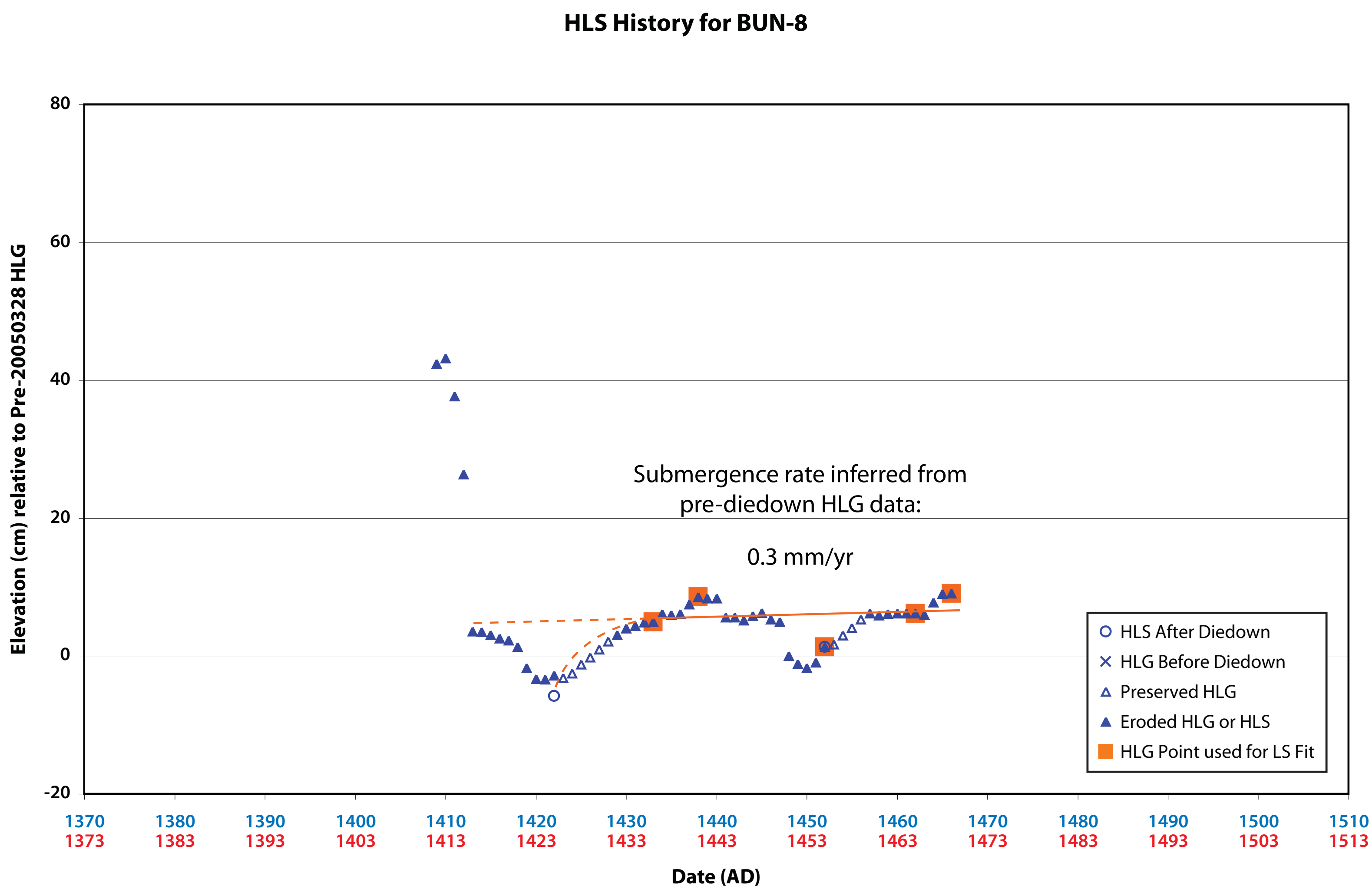

Figure S6b. Relative sea level history derived from slab BUN-8.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

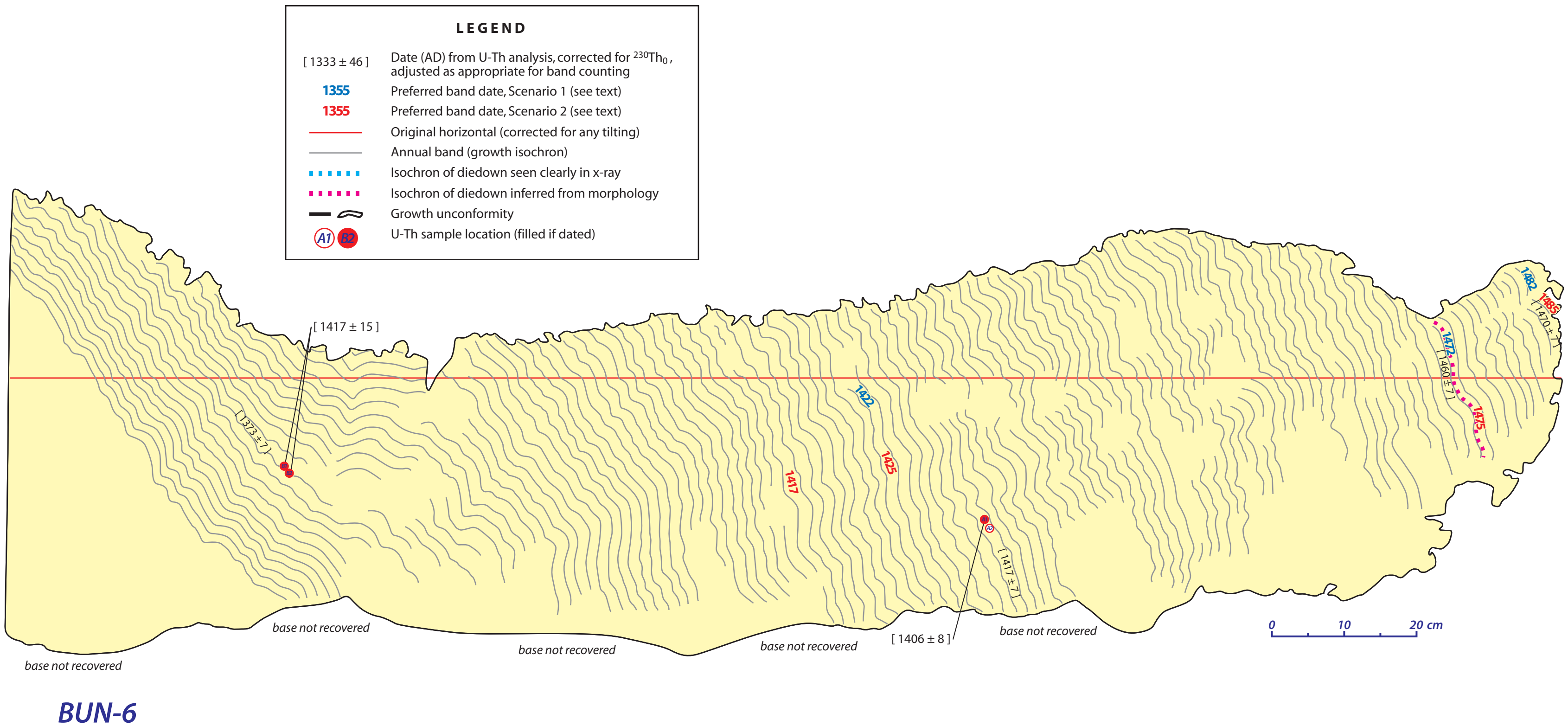

Figure S7a. Cross-section of slab BUN-6, from site BUN-A.

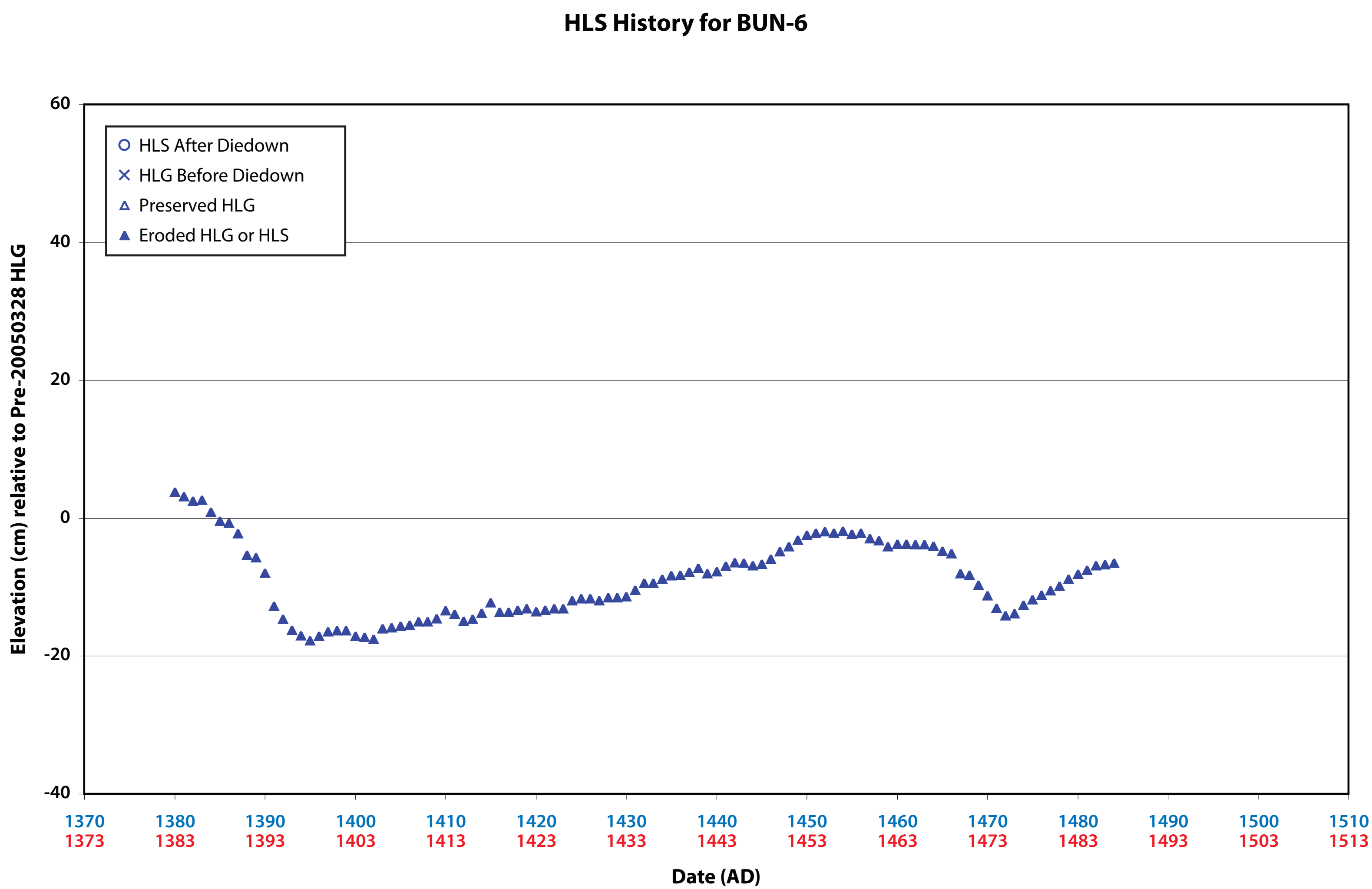

Figure S7b. Relative sea level history derived from slab BUN-6.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

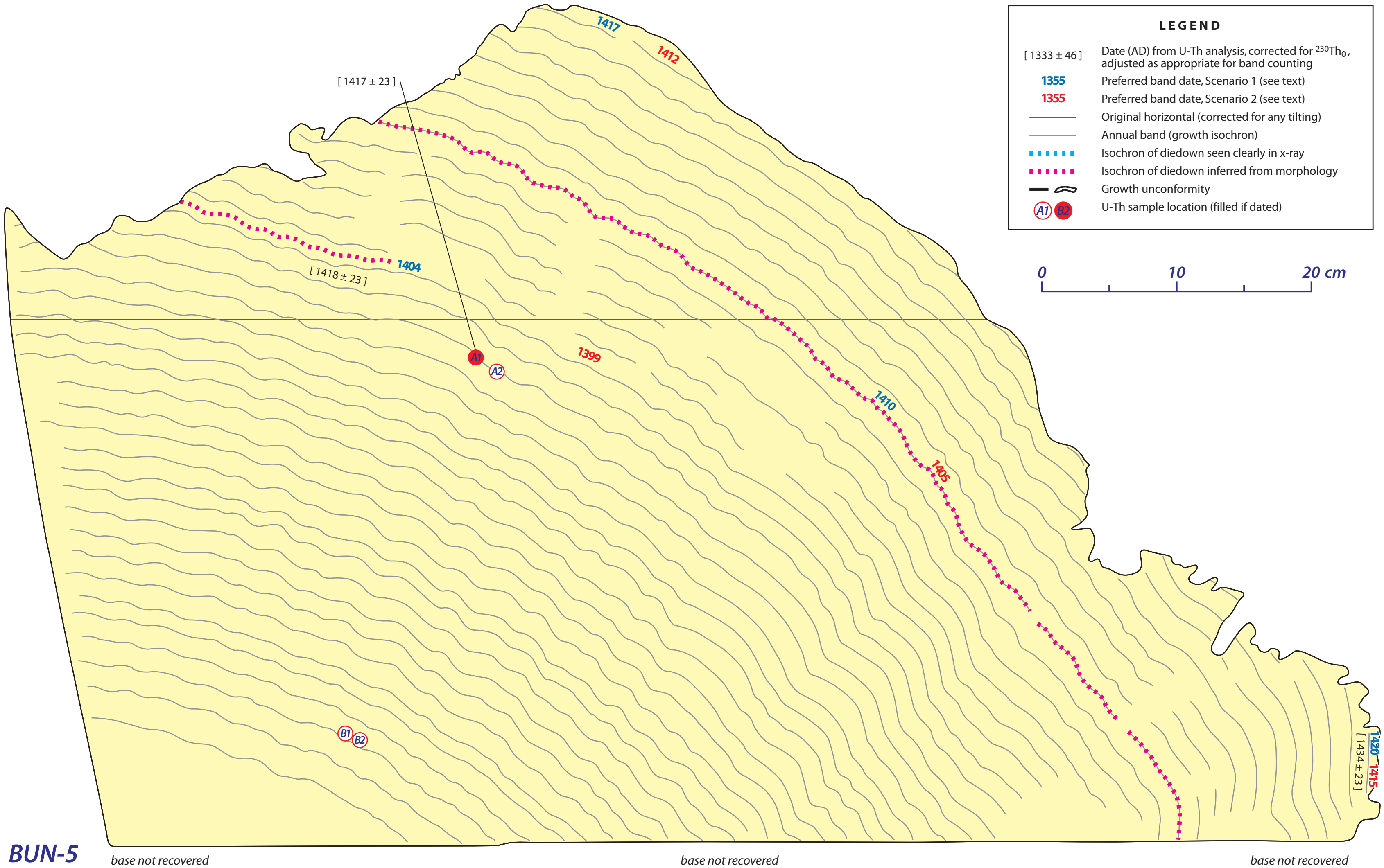

Figure S8a. Cross-section of slab BUN-5, from site BUN-A.

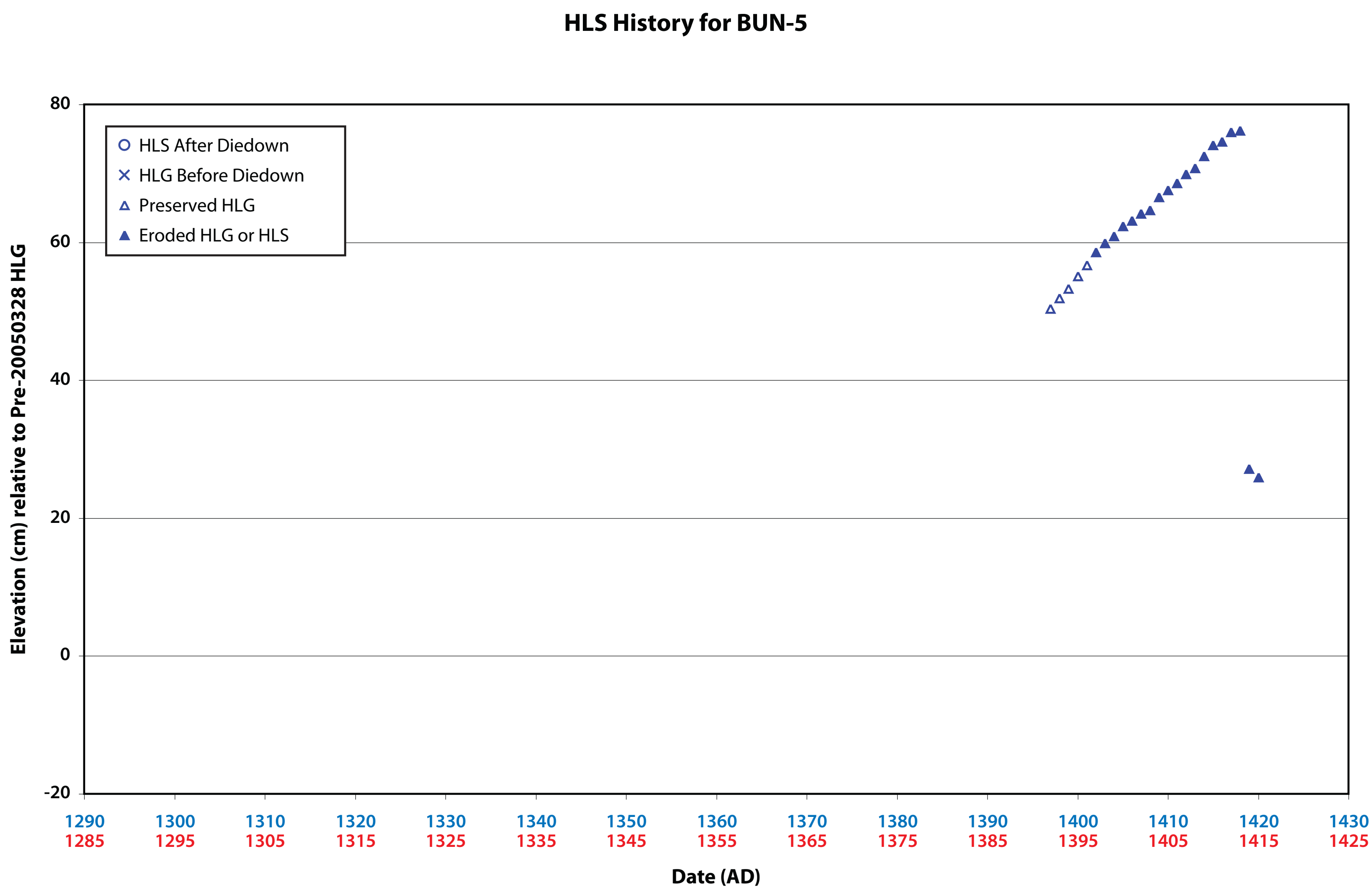

Figure S8b. Relative sea level history derived from slab BUN-5.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

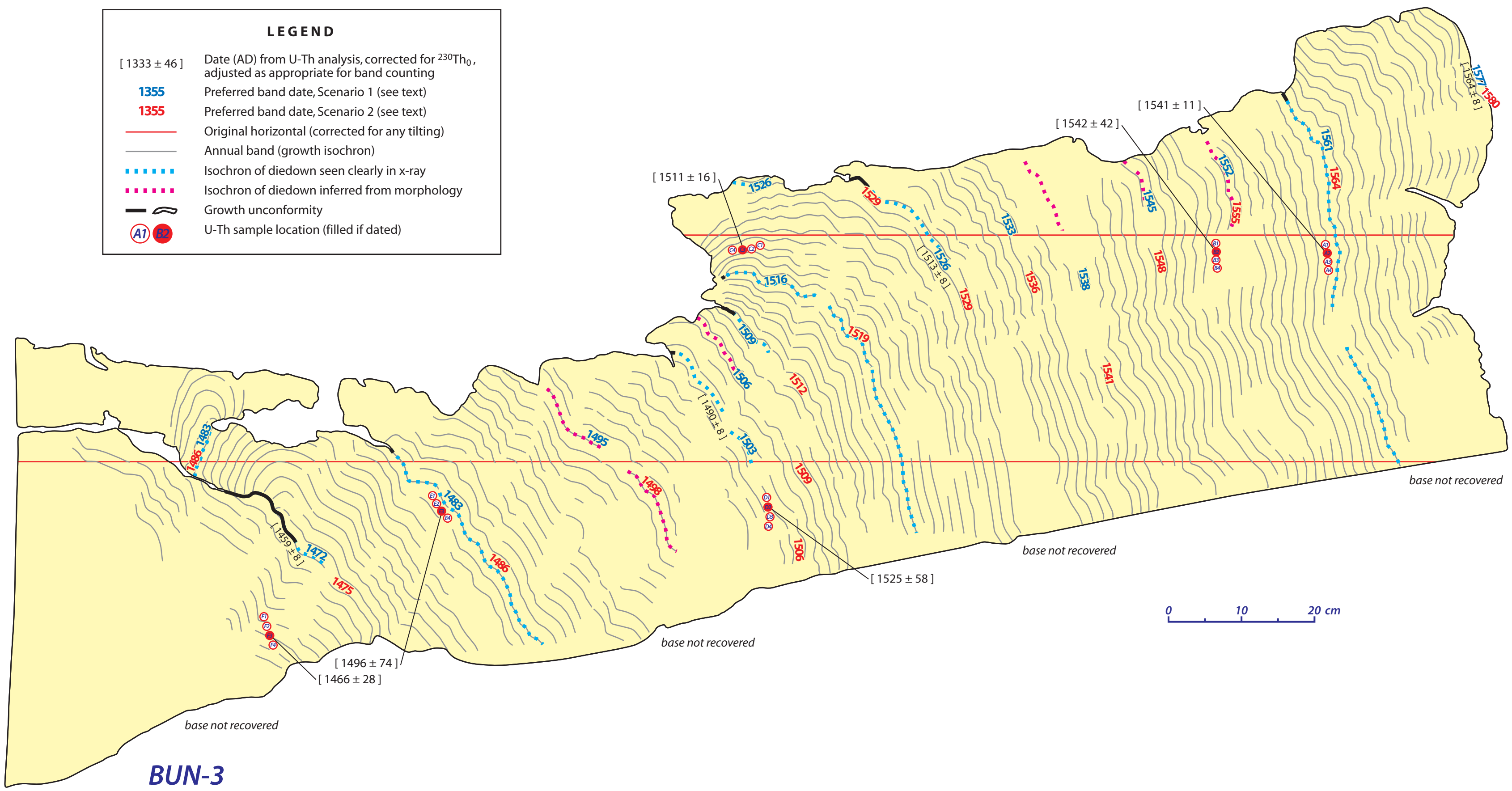

Figure S9a. Cross-section of slab BUN-3, from site BUN-A.

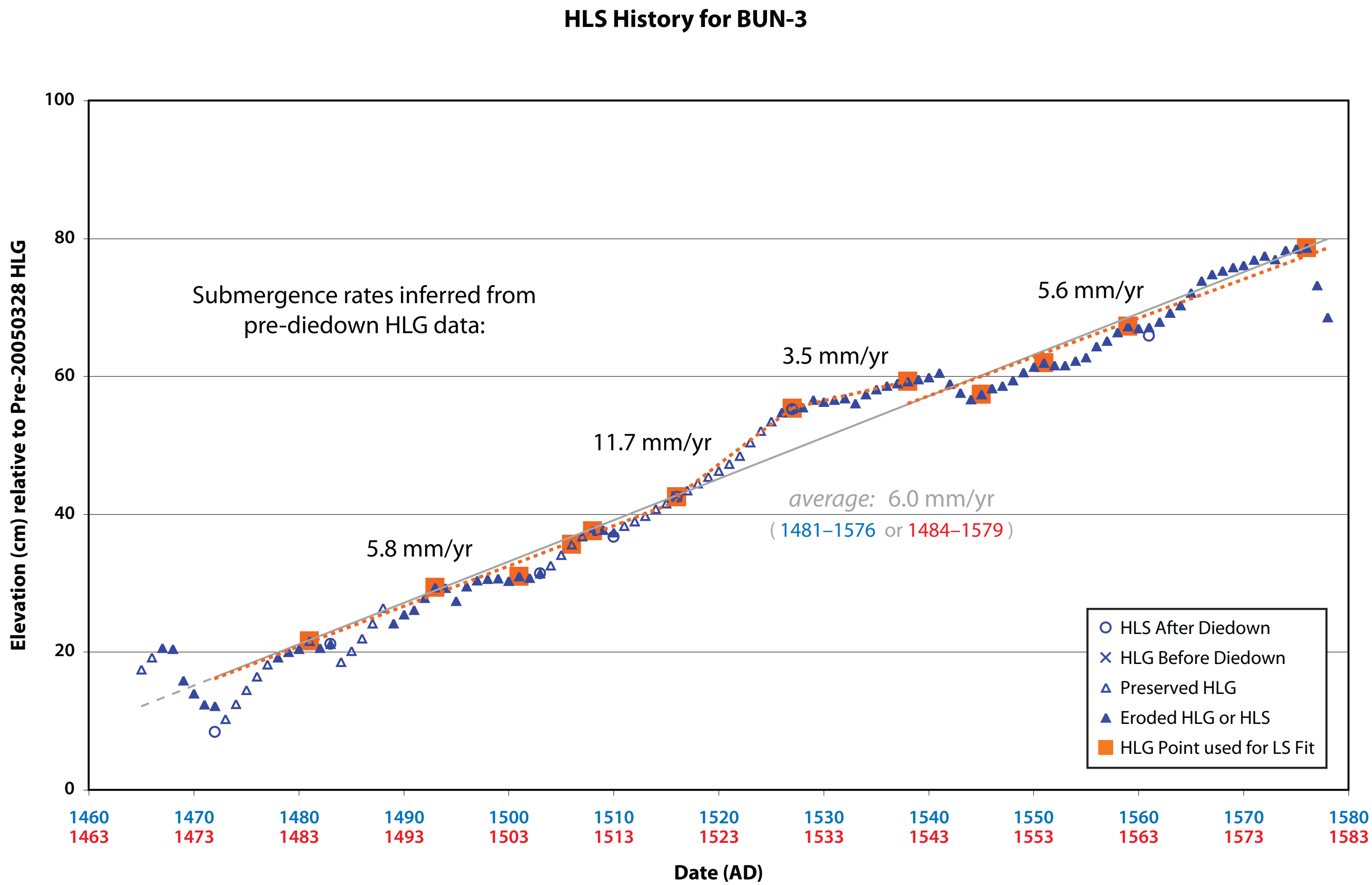

Figure S9b. Relative sea level history derived from slab BUN-3.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

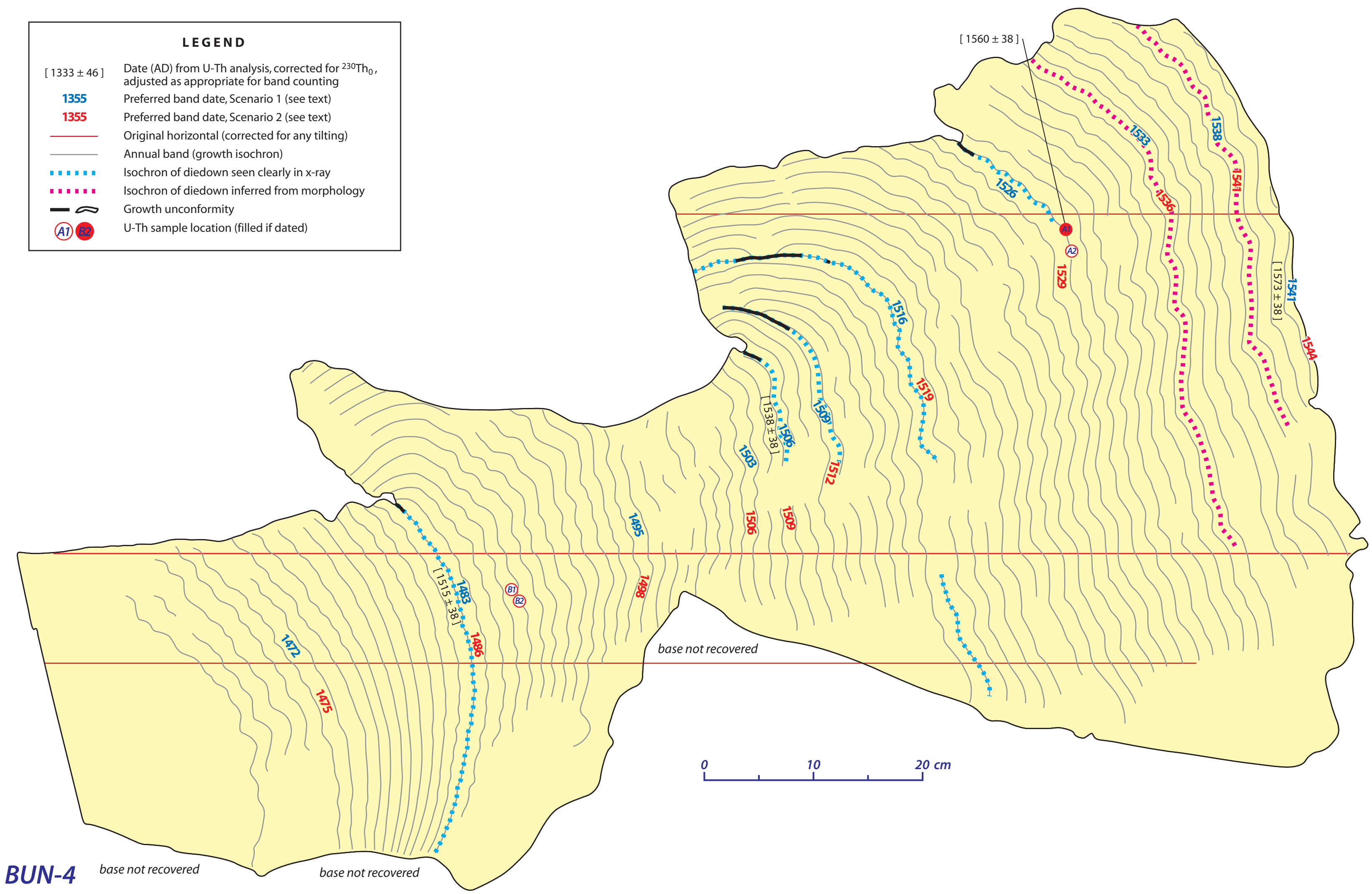

Figure S10a. Cross-section of slab BUN-4, from site BUN-A.

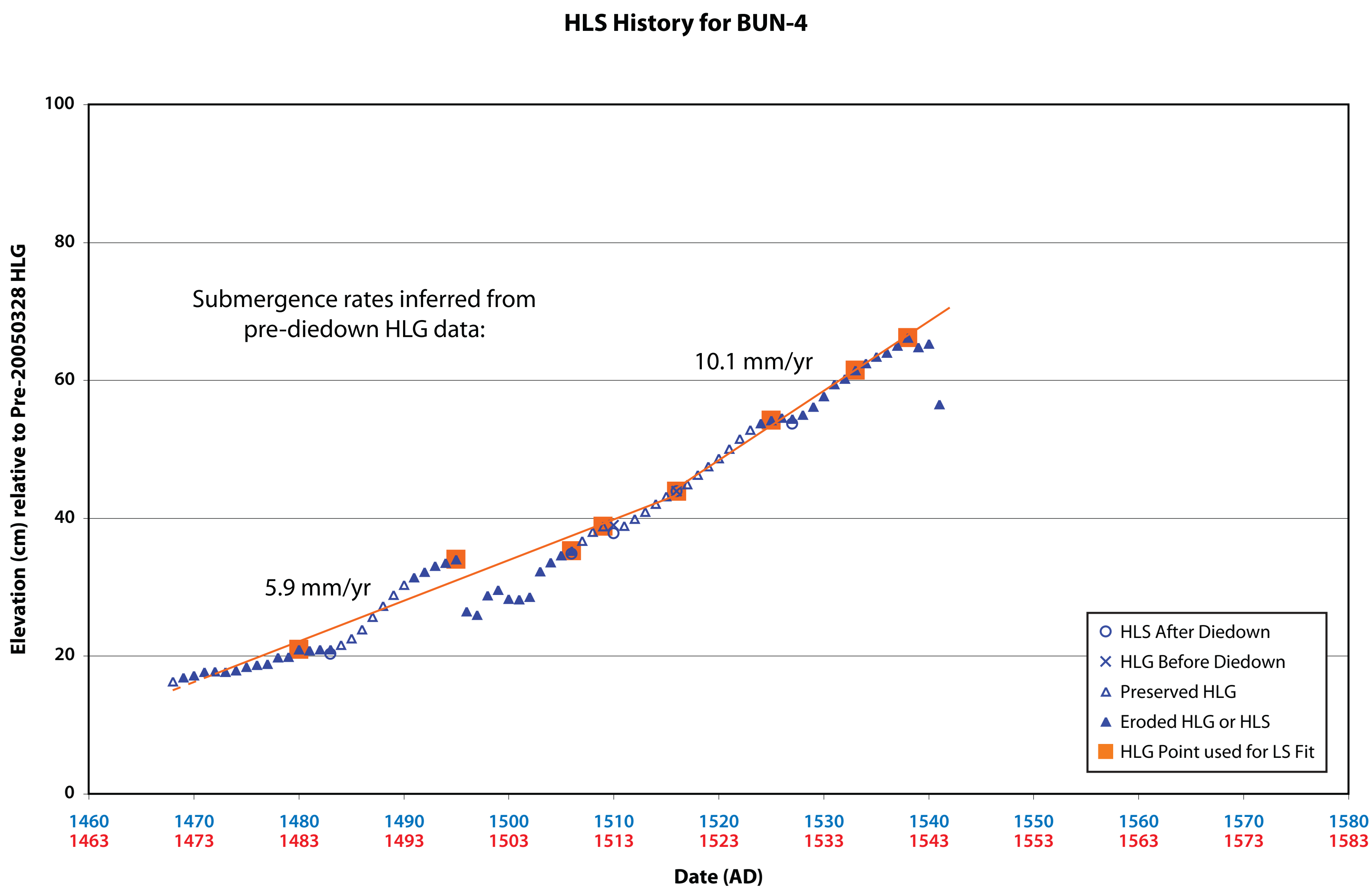

Figure S10b. Relative sea level history derived from slab BUN-4.
On the horizontal axis, blue dates correspond to Scenario 1, whereas red dates correspond to Scenario 2. See text for discussion.

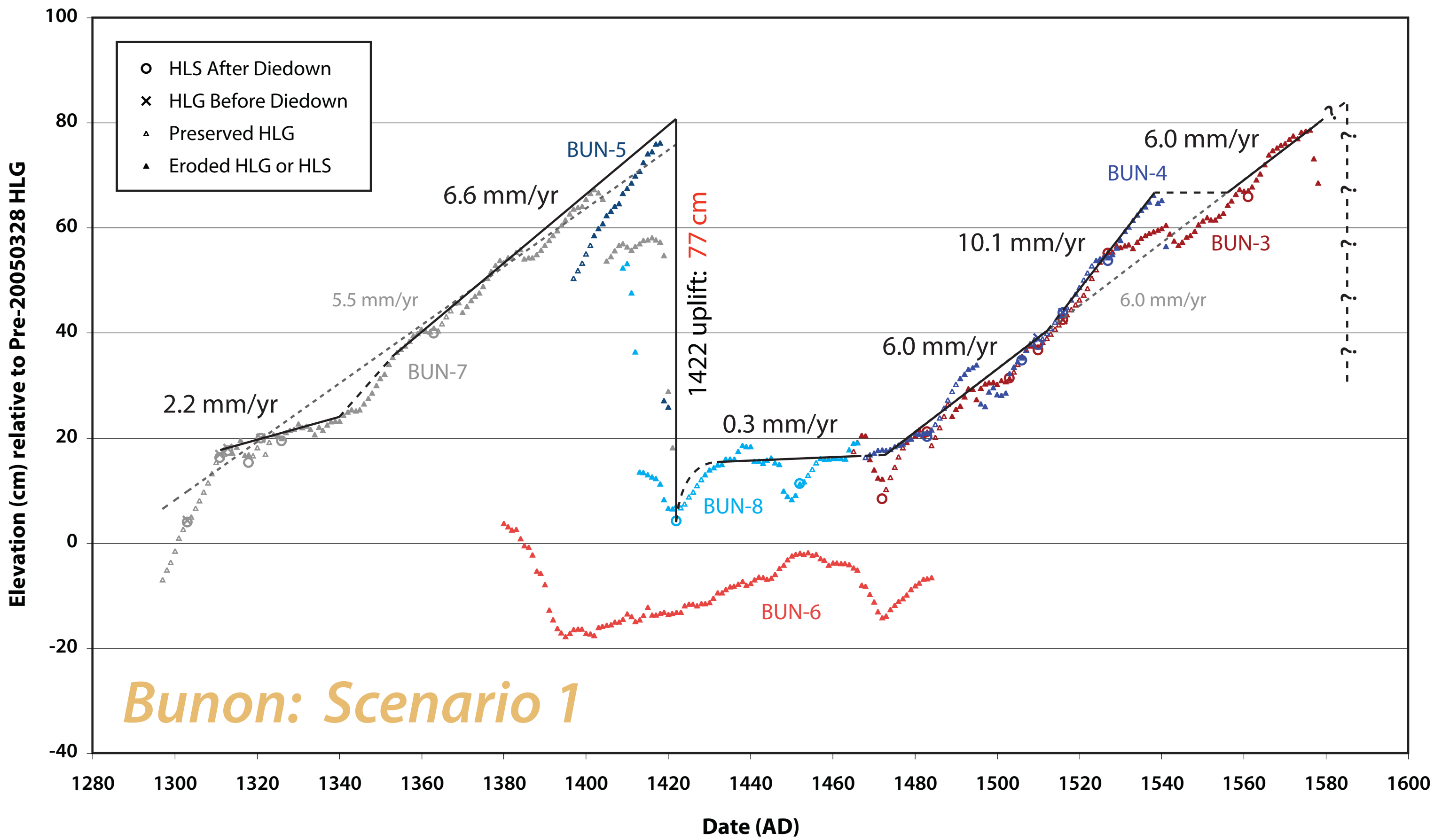

Figure S11a. Relative sea level history (Scenario 1, assuming a single diedown in or around 1422) for the 14th–16th centuries at site BUN-A. The original elevations of BUN-3, BUN-7, and BUN-8 have been restored as discussed in the text. The sea level curve (black) is solid where well constrained by data, dotted where averaged over long periods, dashed where inferred, and queried where conjectural.

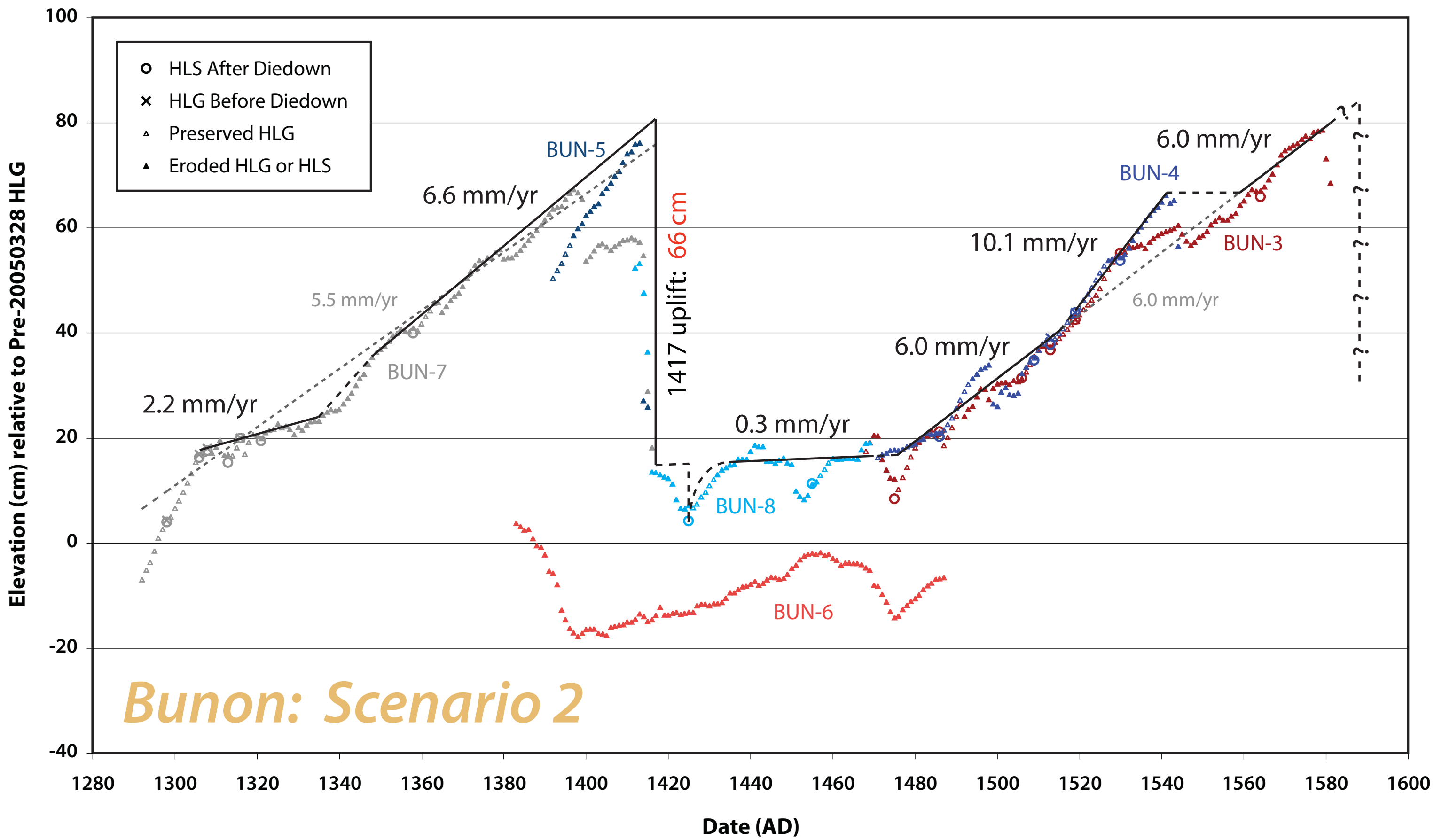

Figure S11b. Relative sea level history (Scenario 2, assuming a dual diedown in 1417 and 1425) for the 14th–16th centuries at site BUN-A. The original elevations of BUN-3, BUN-7, and BUN-8 have been restored as discussed in the text. The sea level curve (black) is solid where well constrained by data, dotted where averaged over long periods, dashed where inferred, and queried where conjectural.

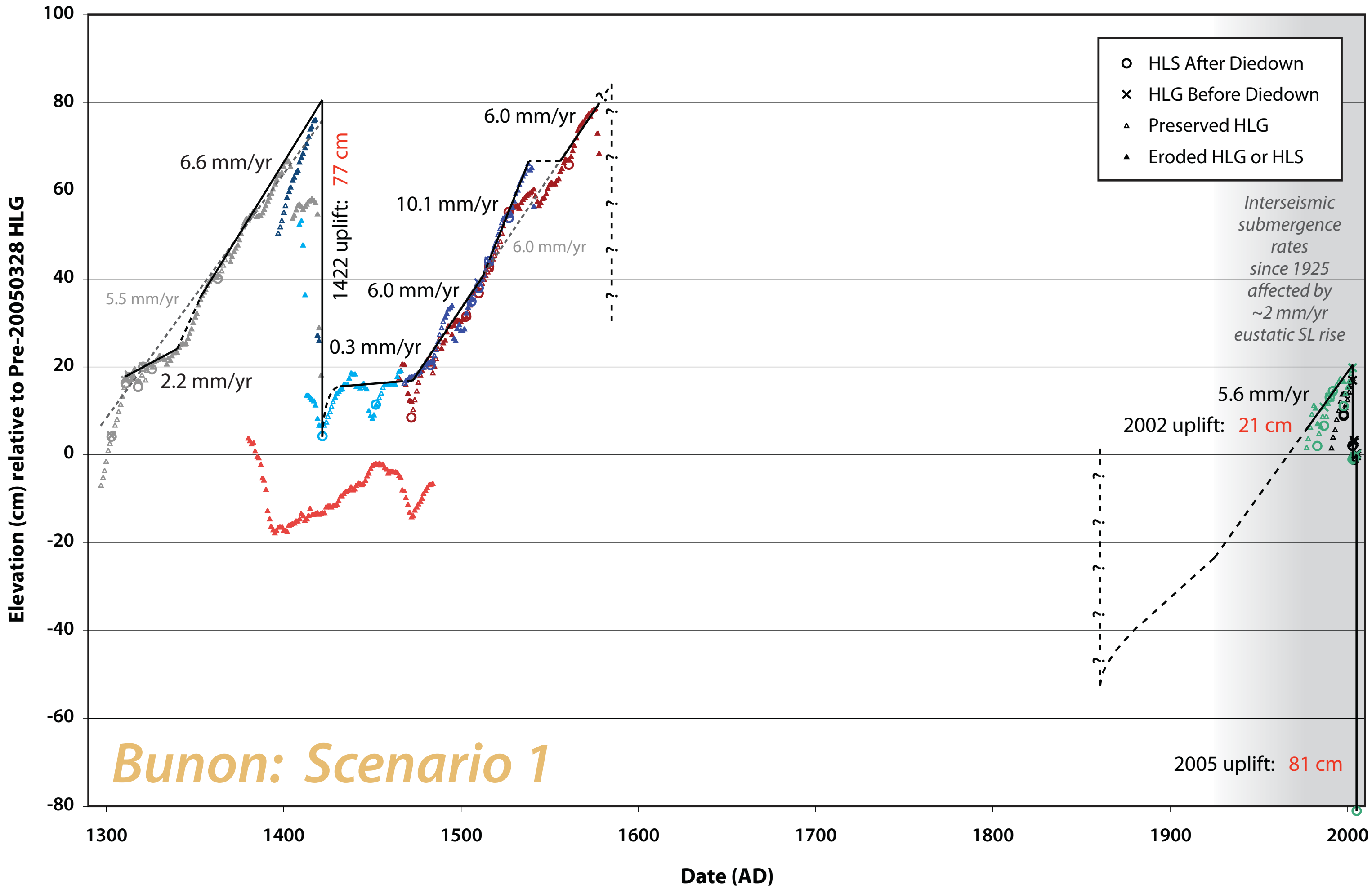

Figure S11c. BUN-A relative sea level history (Scenario 1, assuming a single diedown in 1422) from the 14th century through the present. The original elevations of BUN-3, BUN-7, and BUN-8 have been restored as discussed in the text. Note that these rates and elevations are influenced by eustatic change and hydroisostasy; such signals must be removed before tectonic uplift and subsidence can be determined. Relative sea level must have fallen considerably between the 16th and 20th centuries, probably a result of net uplift. It is likely that one or more earthquakes are missing from the record since 1575. We infer from observations elsewhere on southern Simeulue [*Meltzner et al.*, 2009] that Bunon was uplifted during the 1861 southern Simeulue–Nias earthquake, but we have no evidence to either confirm or refute this at Bunon.

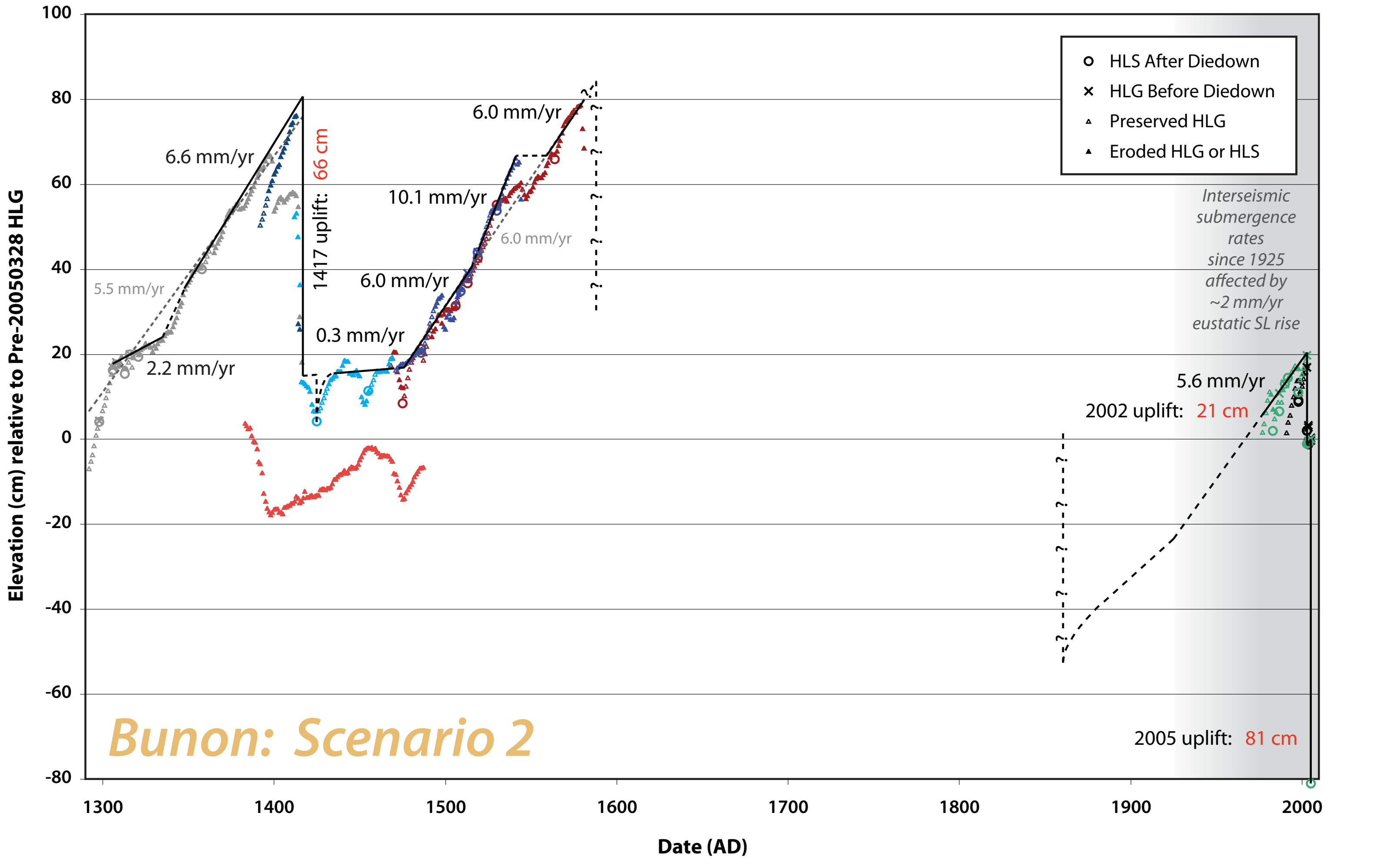

Figure S11d. BUN-A relative sea level history (Scenario 2, assuming a dual diedown in 1417 and 1425), 14th century through the present. The original elevations of BUN-3, BUN-7, and BUN-8 have been restored as discussed in the text. Note that these rates and elevations are influenced by eustatic change and hydroisostasy; such signals must be removed before tectonic uplift and subsidence can be determined. Relative sea level must have fallen considerably between the 16th and 20th centuries, probably a result of net uplift. It is likely that one or more earthquakes are missing from the record since 1575. We infer from observations elsewhere on southern Simeulue [*Meltzner et al.*, 2009] that Bunon was uplifted during the 1861 southern Simeulue–Nias earthquake, but we have no evidence to either confirm or refute this at Bunon.

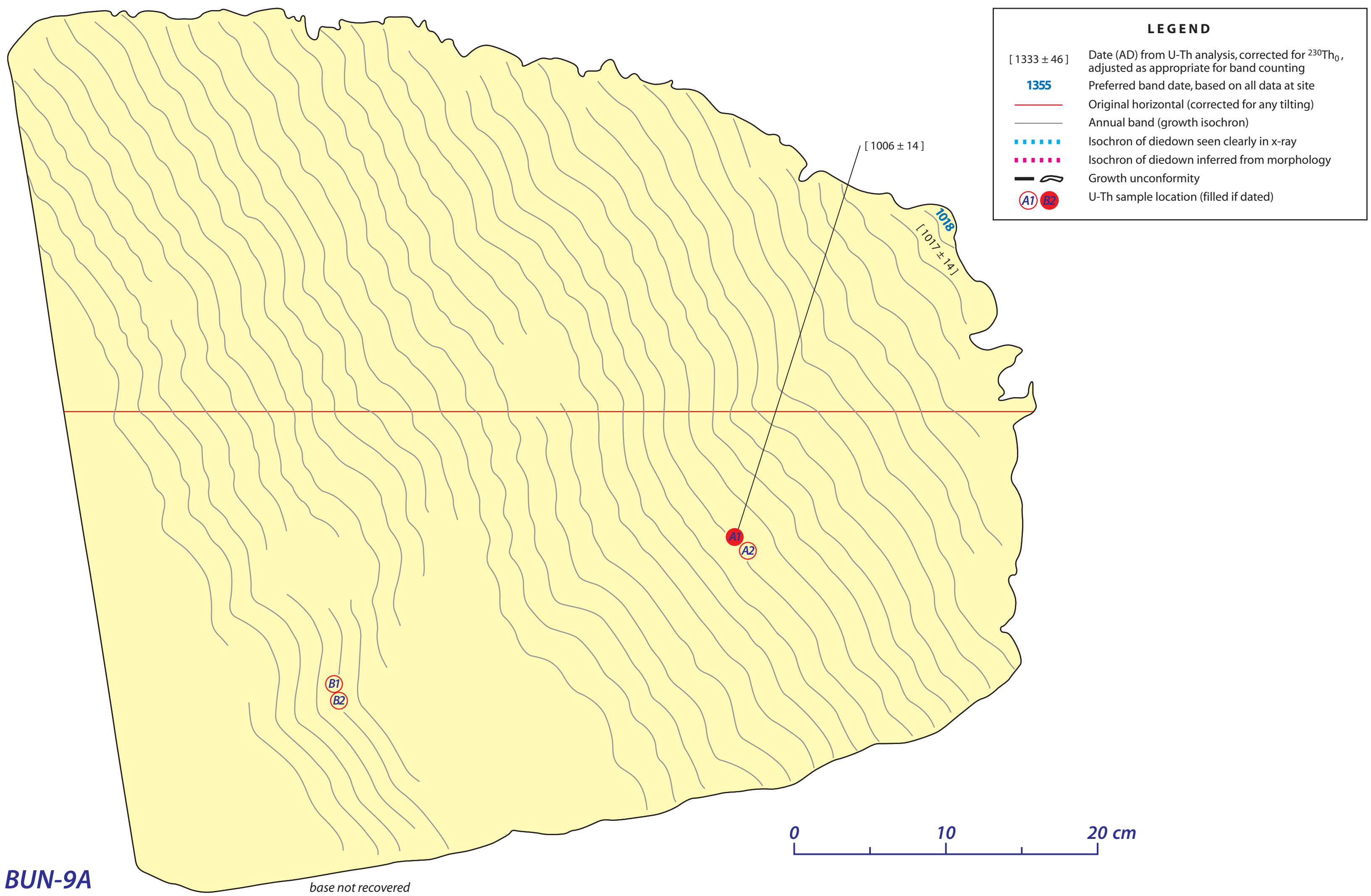

Figure S12a. Cross-section of slab BUN-9A, from site BUN-A.

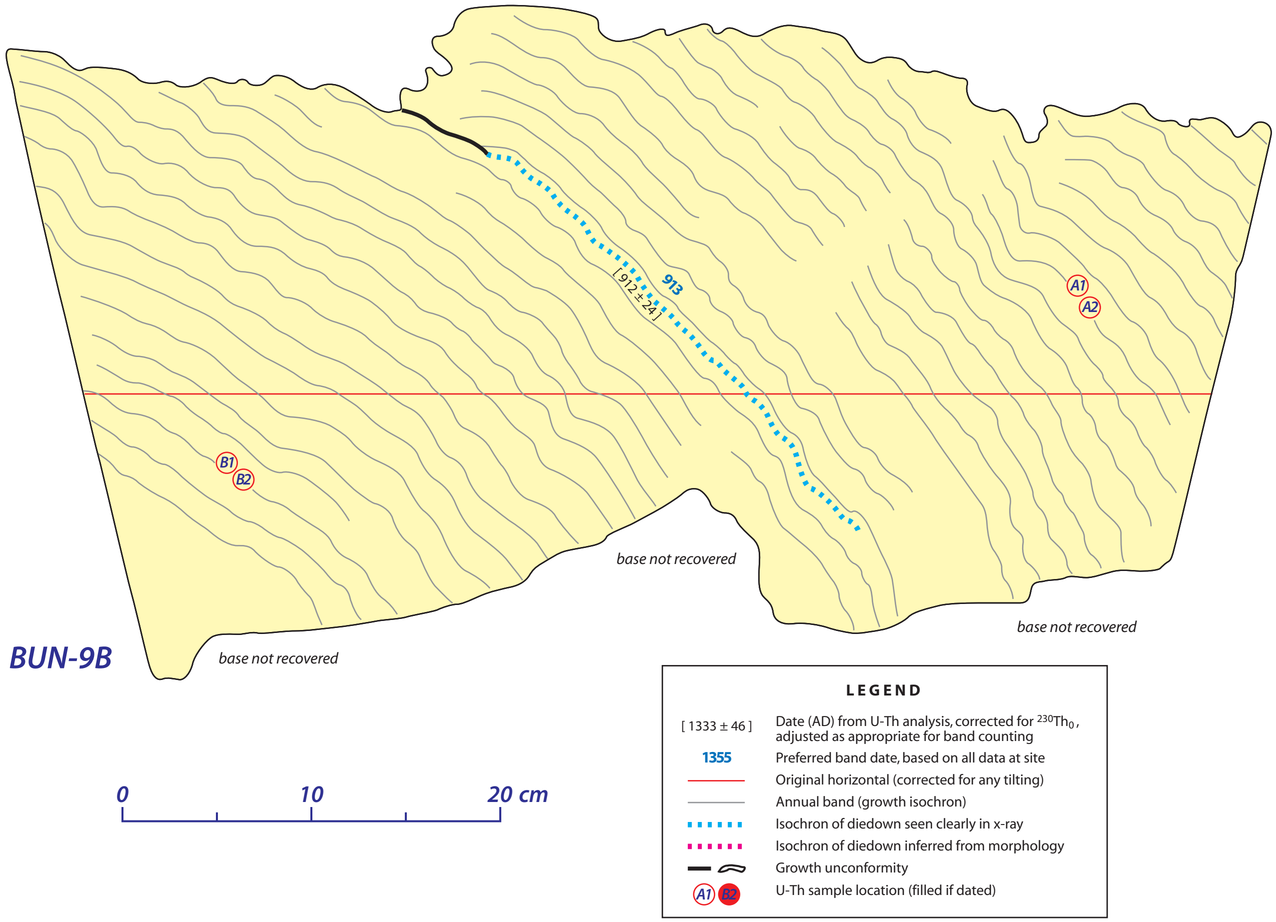

Figure S12b. Cross-section of slab BUN-9B, from site BUN-A.

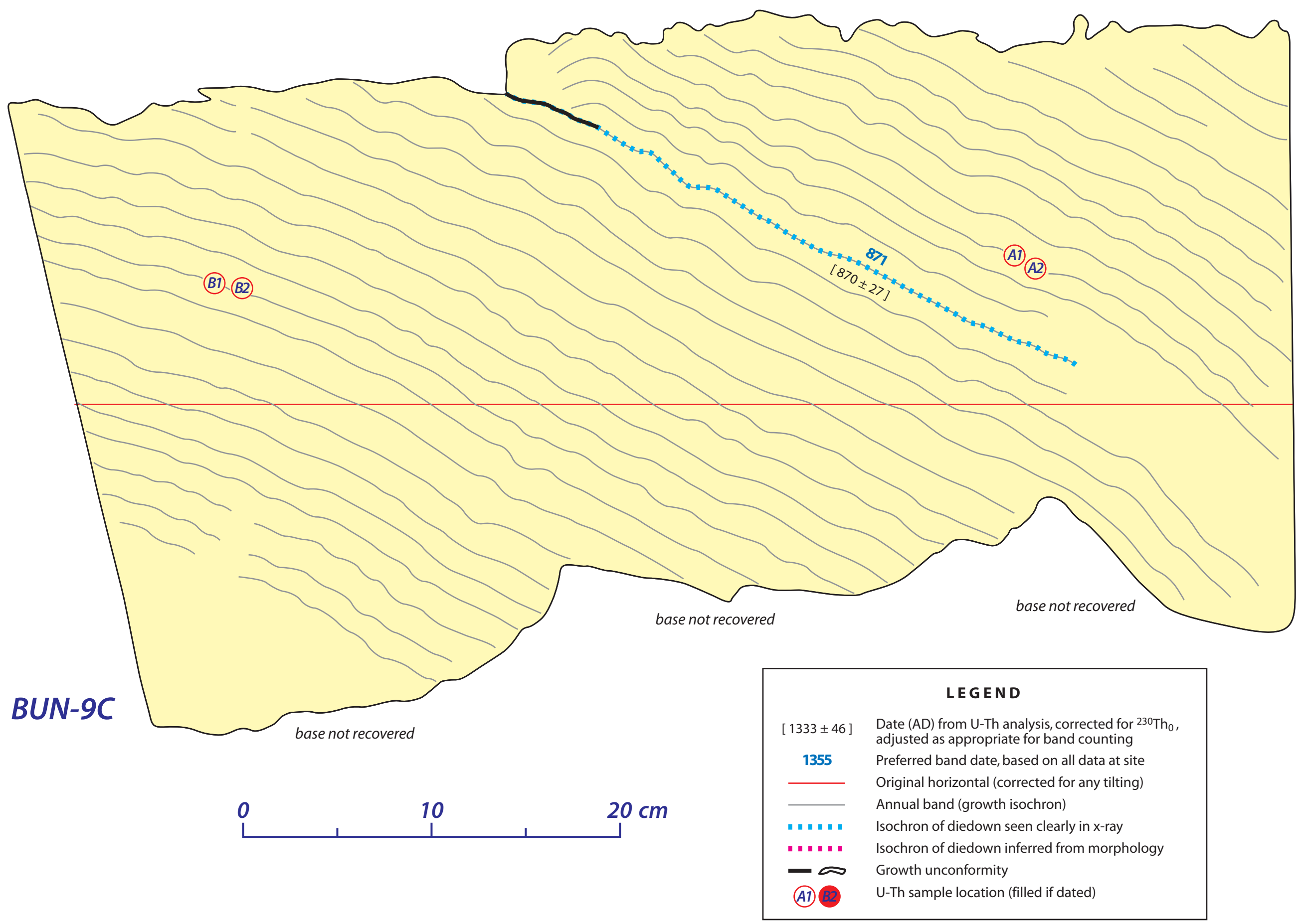

Figure S12c. Cross-section of slab BUN-9C, from site BUN-A.

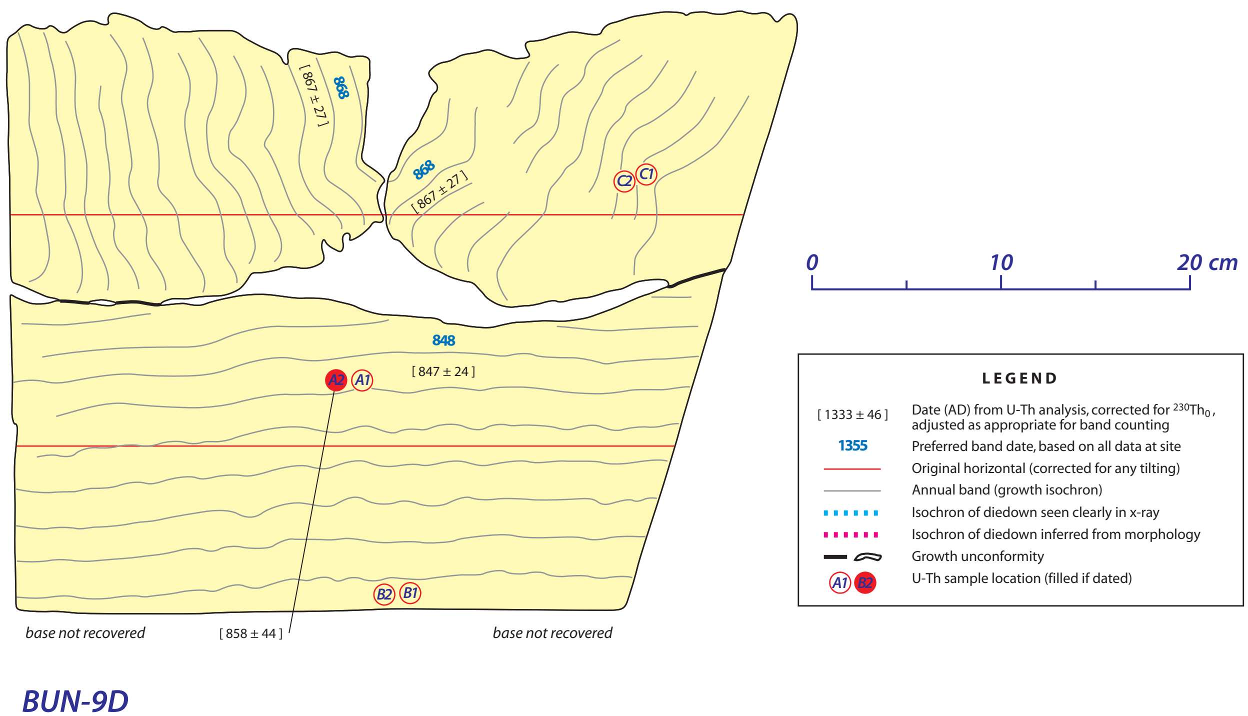

Figure S12d. Cross-section of slab BUN-9D, from site BUN-A.

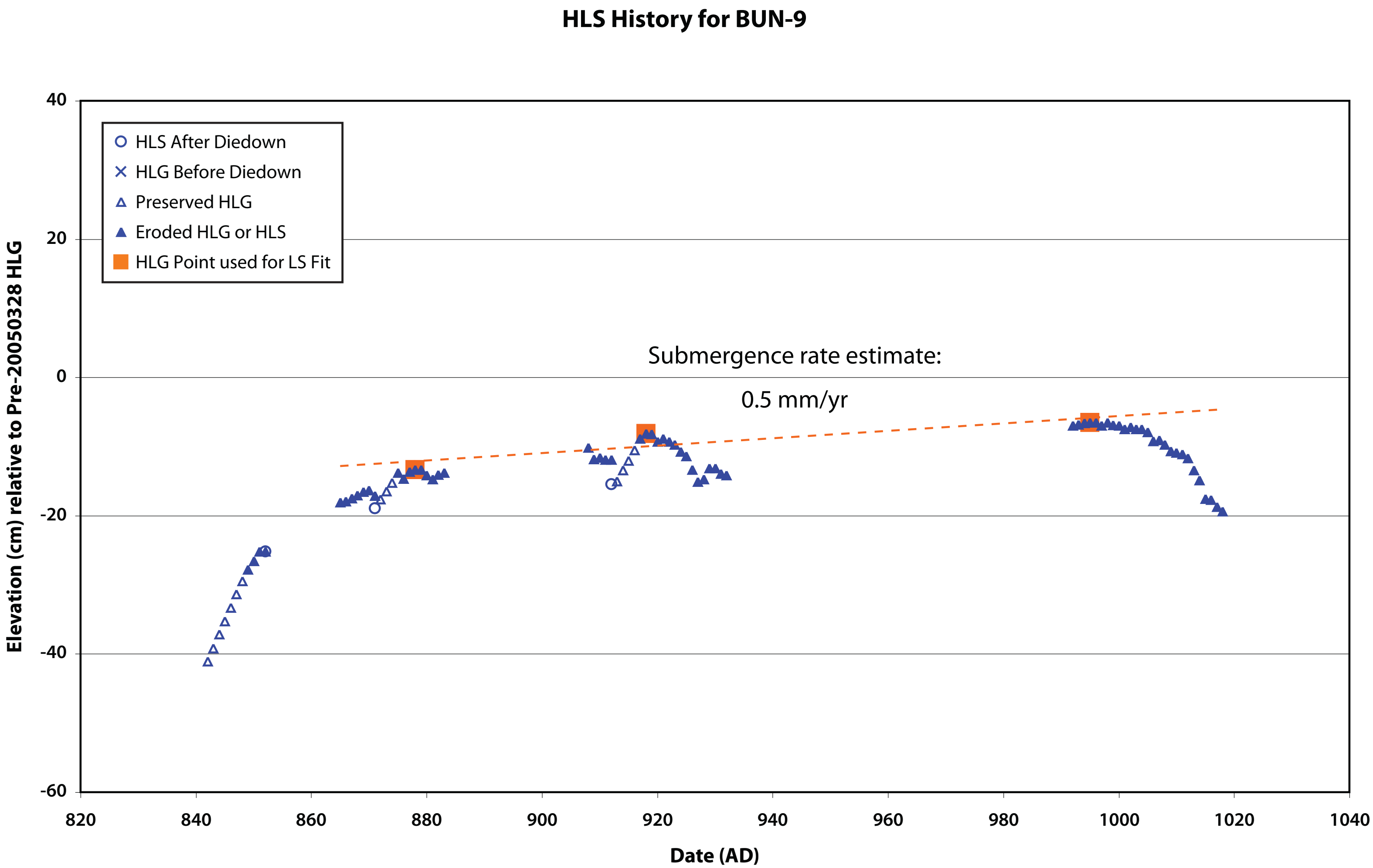

Figure S12e. Relative sea level history derived from head BUN-9.

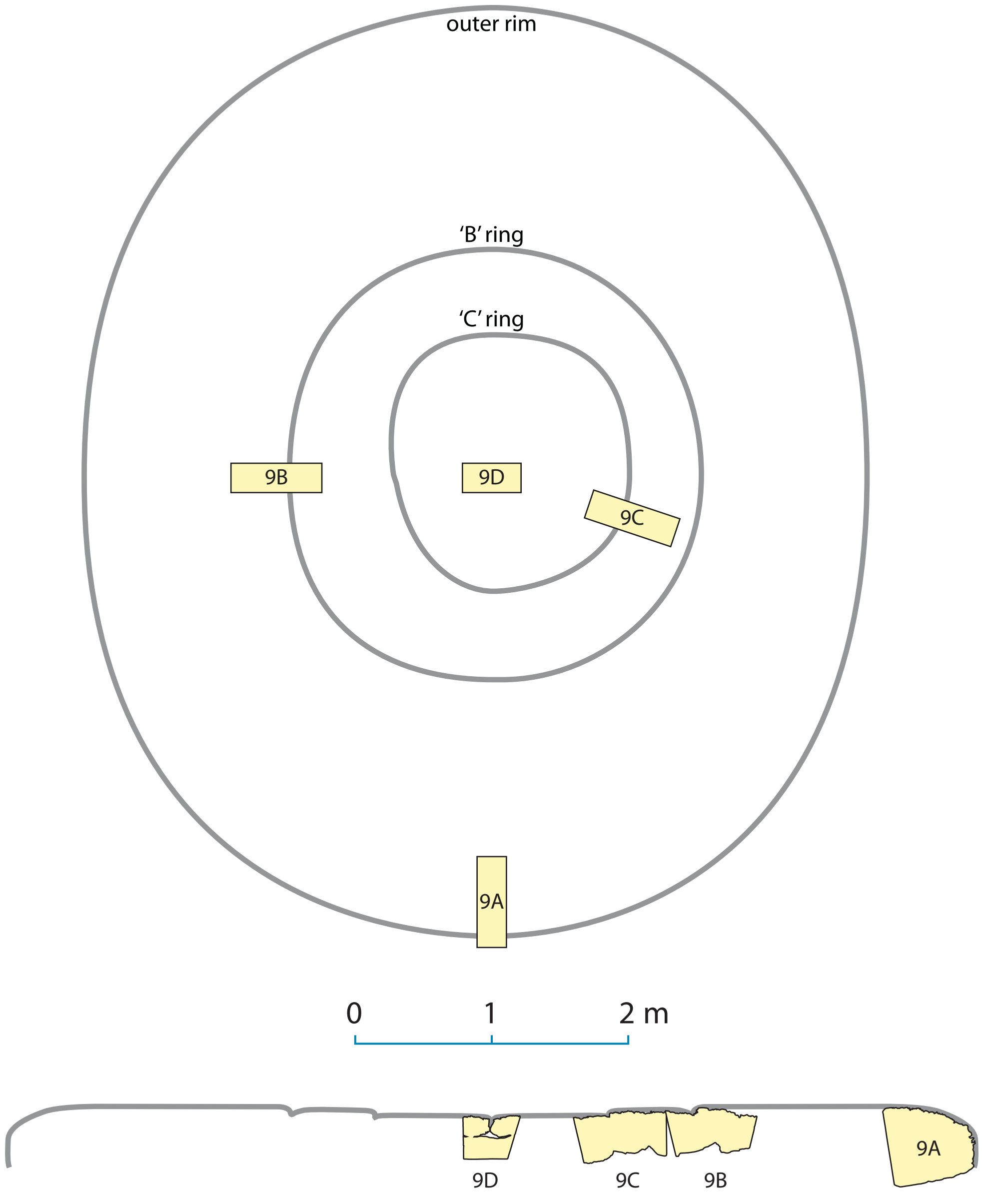

Figure S12f. *Top:* Map-view sketch of microatoll BUN-9, showing the relative location of each slab and the head's nearly concentric rings. *Bottom:* An idealized profile of BUN-9, with all slabs projected radially onto this profile. The map-view sketch and the profile are at the same scale, with no vertical exaggeration in the profile. The concentric rings seen in map view are clear diedowns in slabs 9B and 9C.

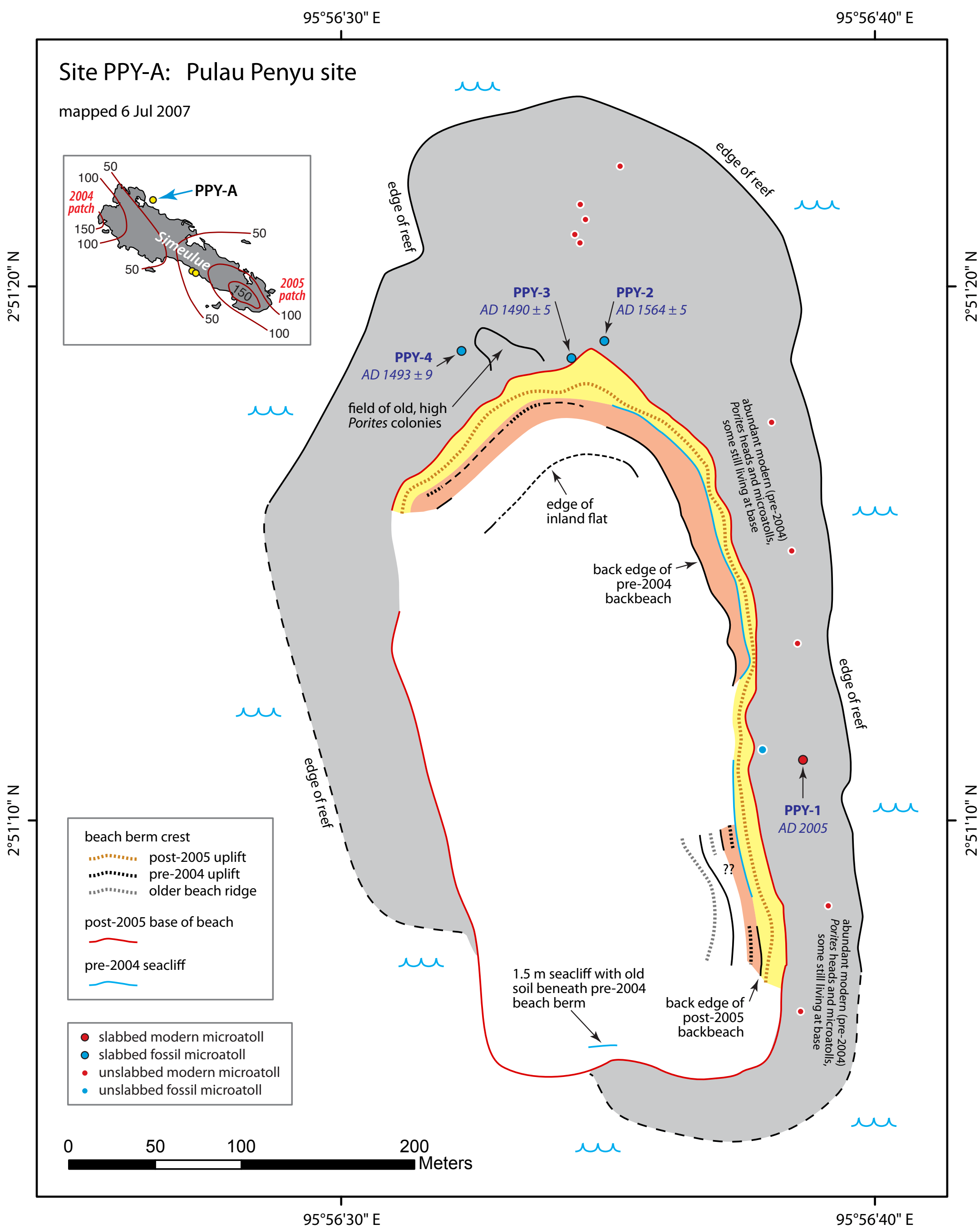

Figure S13. Map of site PPY-A, northeast coast of Simeulue, showing sampled microatolls and their dates of death. Inset shows the relative location of the PPY-A site on Simeulue, along with contours of cumulative uplift (in centimeters) in 2004 and 2005, modified from *Briggs et al.* [2006]. The locus of uplift on the northwestern part of the island is attributed to the 2004 earthquake, whereas the southeastern locus of uplift occurred in 2005.

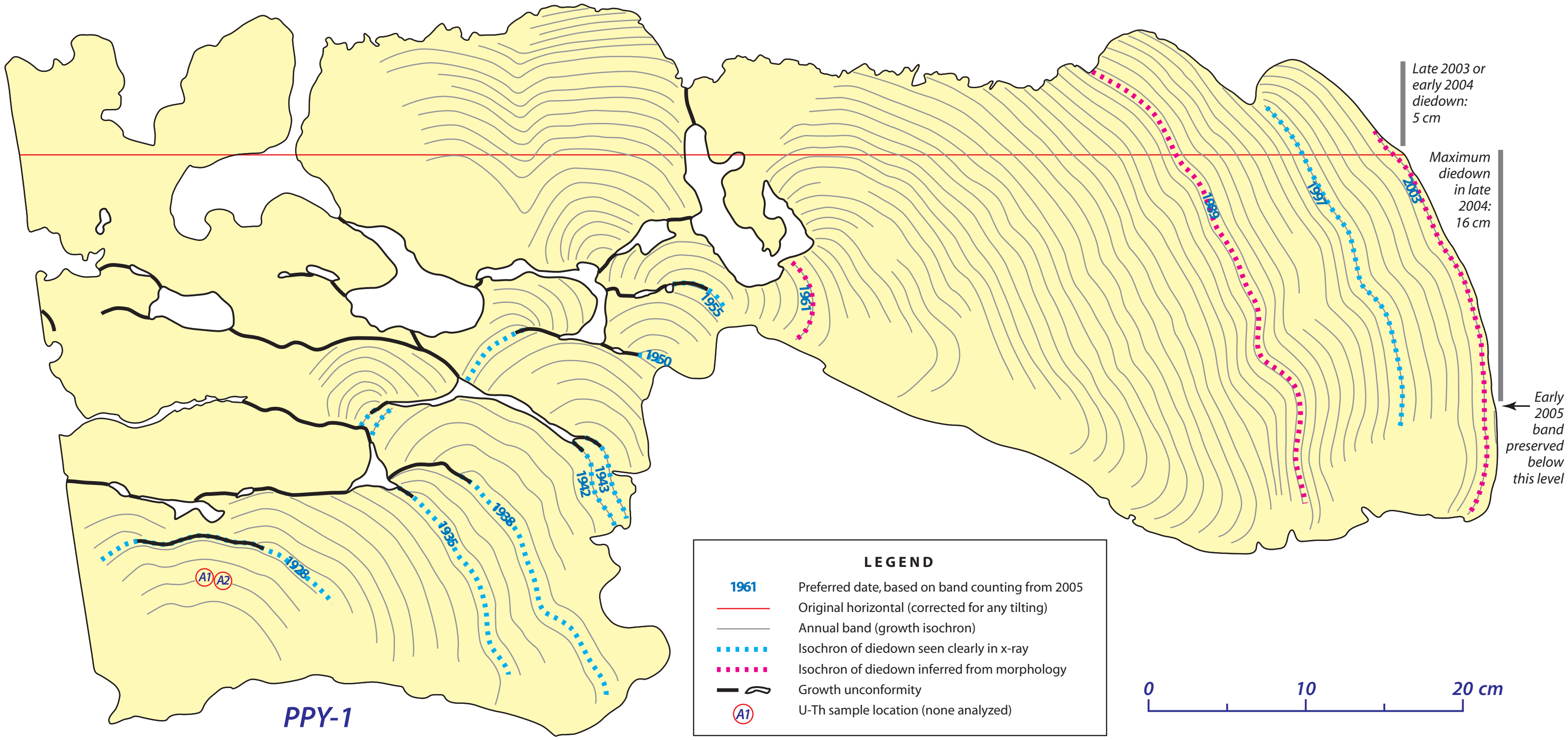

Figure S14a. Cross-section of slab PPY-1, from site PPY-A.

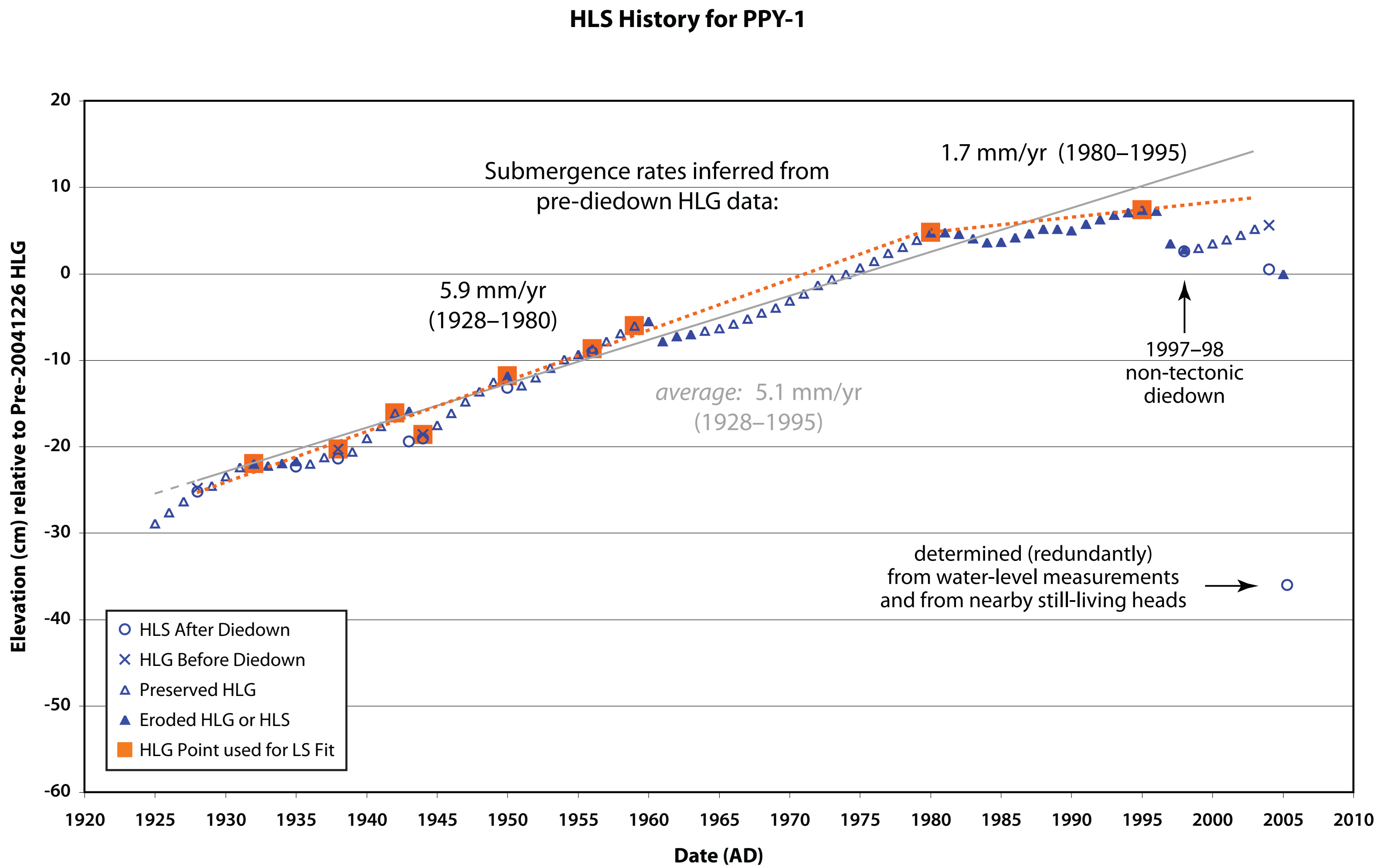

Figure S14b. Relative sea level history derived from slab PPY-1.

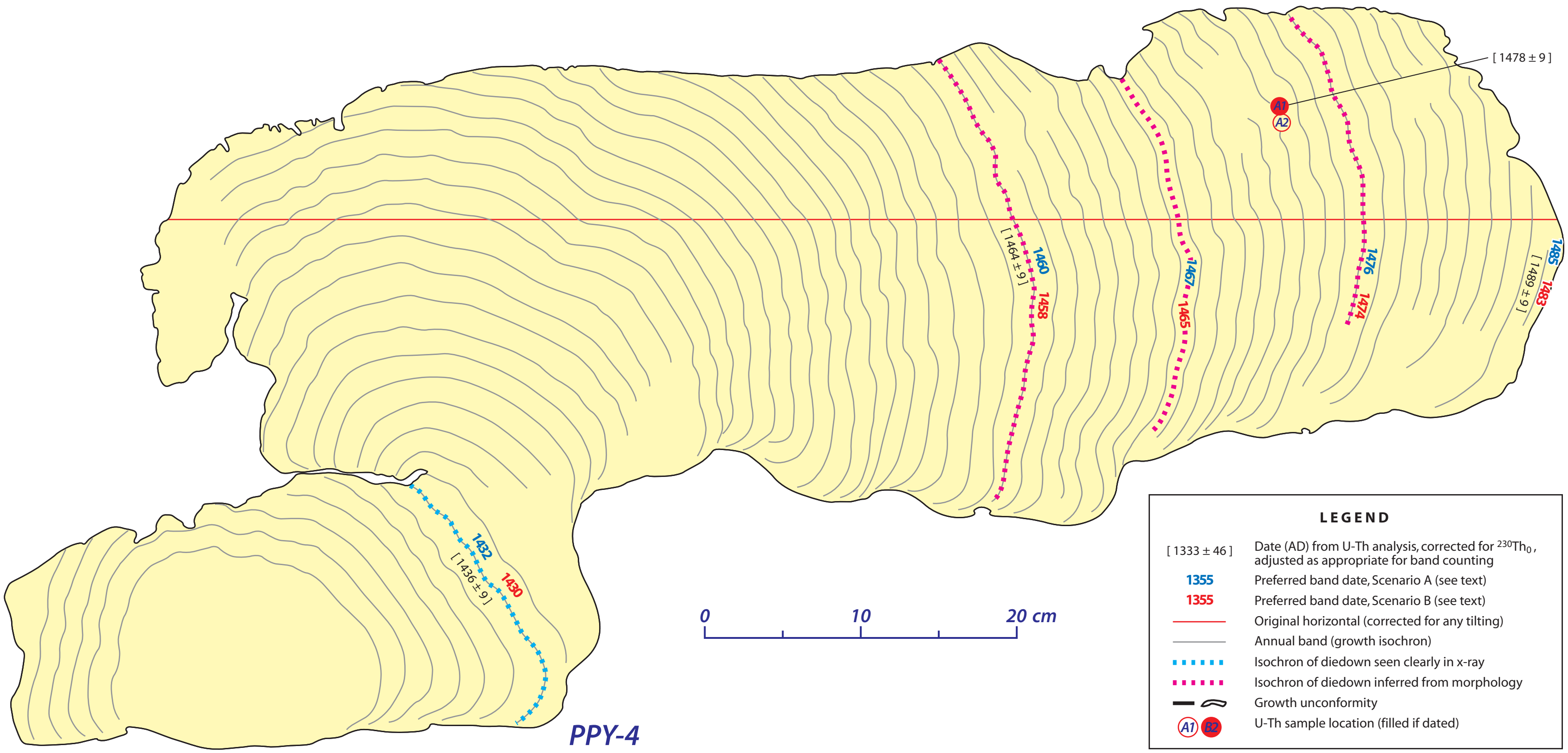

Figure S15a. Cross-section of slab PPY-4, from site PPY-A.

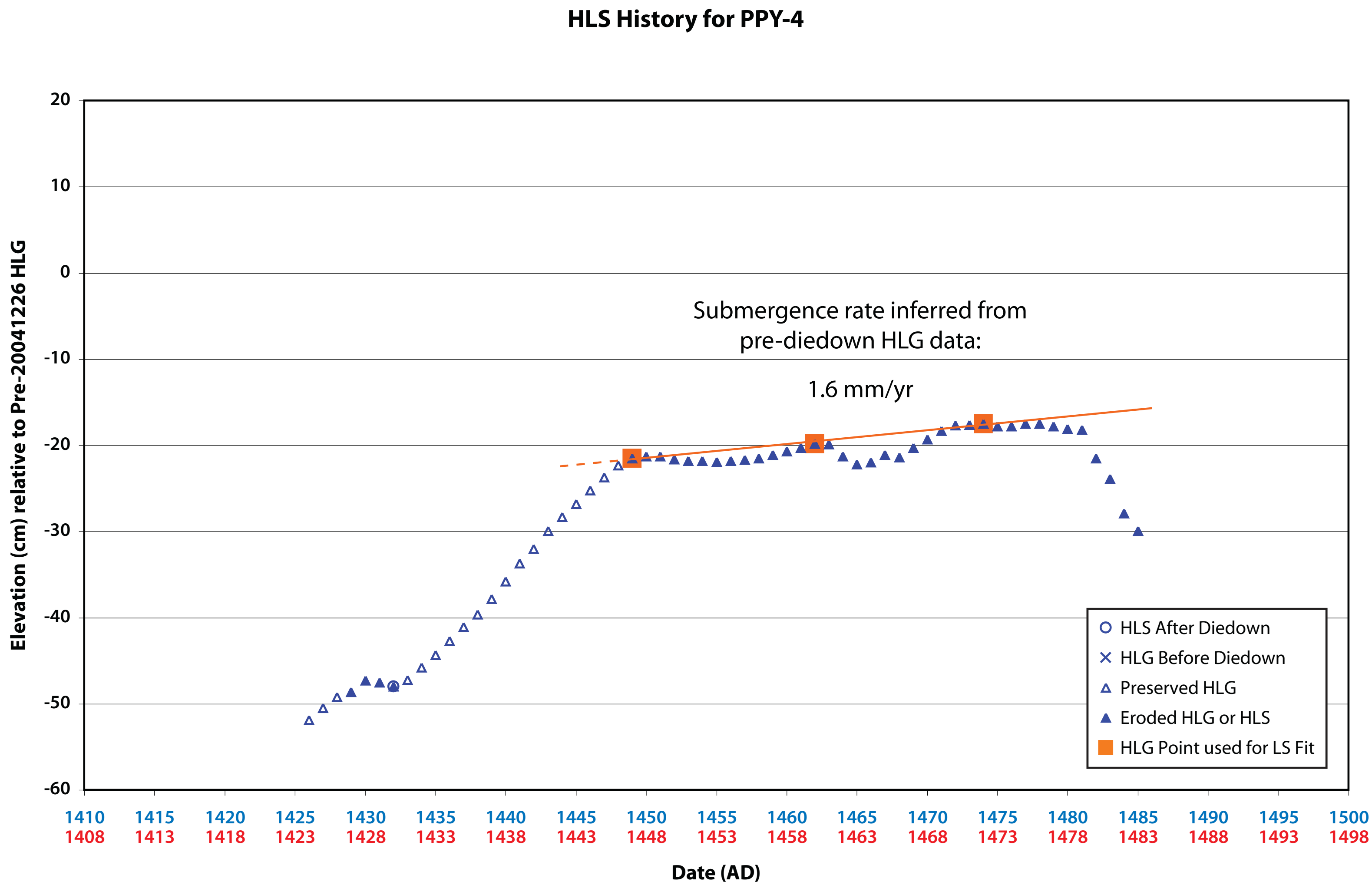

Figure S15b. Relative sea level history derived from slab PPY-4.
On the horizontal axis, blue dates correspond to Scenario A, whereas red dates correspond to Scenario B. See text for discussion.

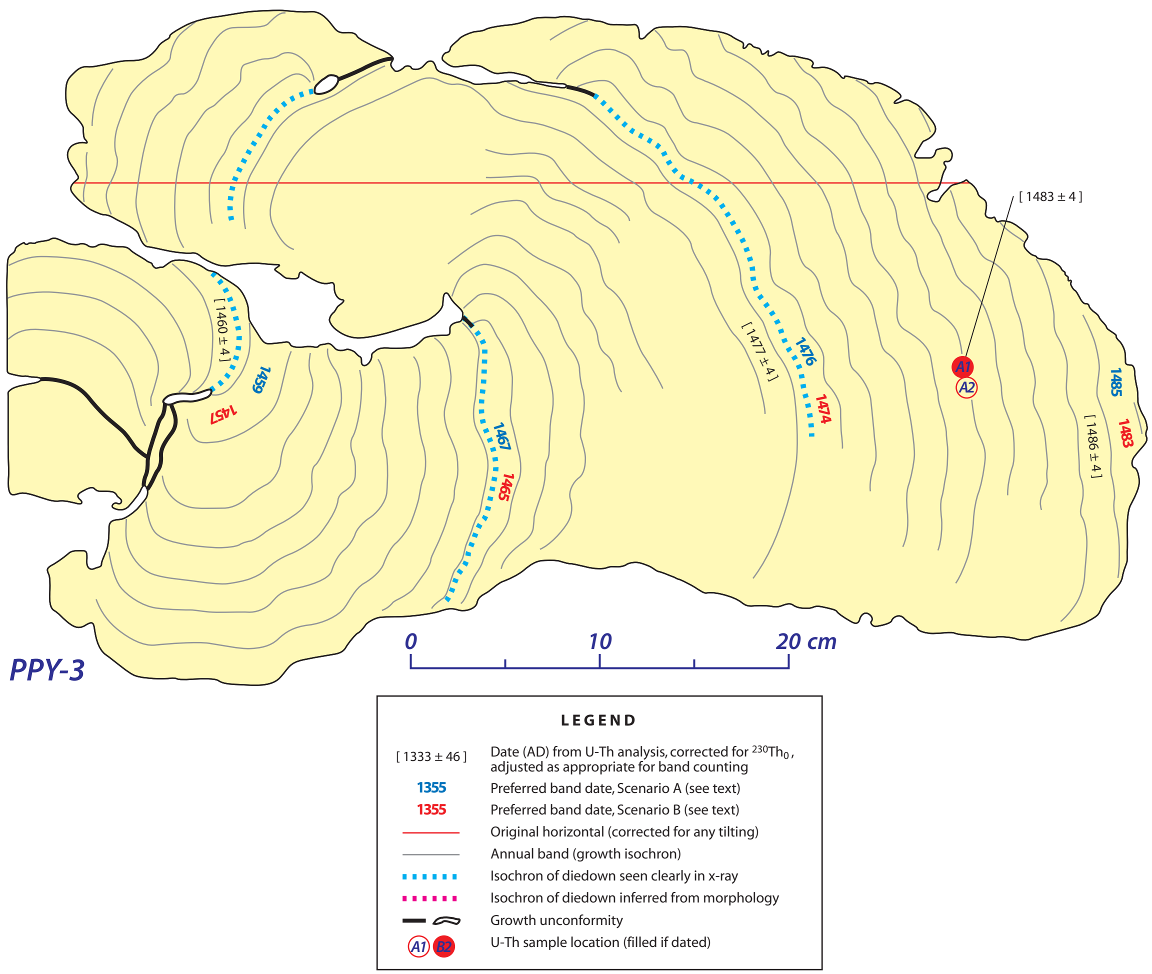

Figure S16a. Cross-section of slab PPY-3, from site PPY-A.

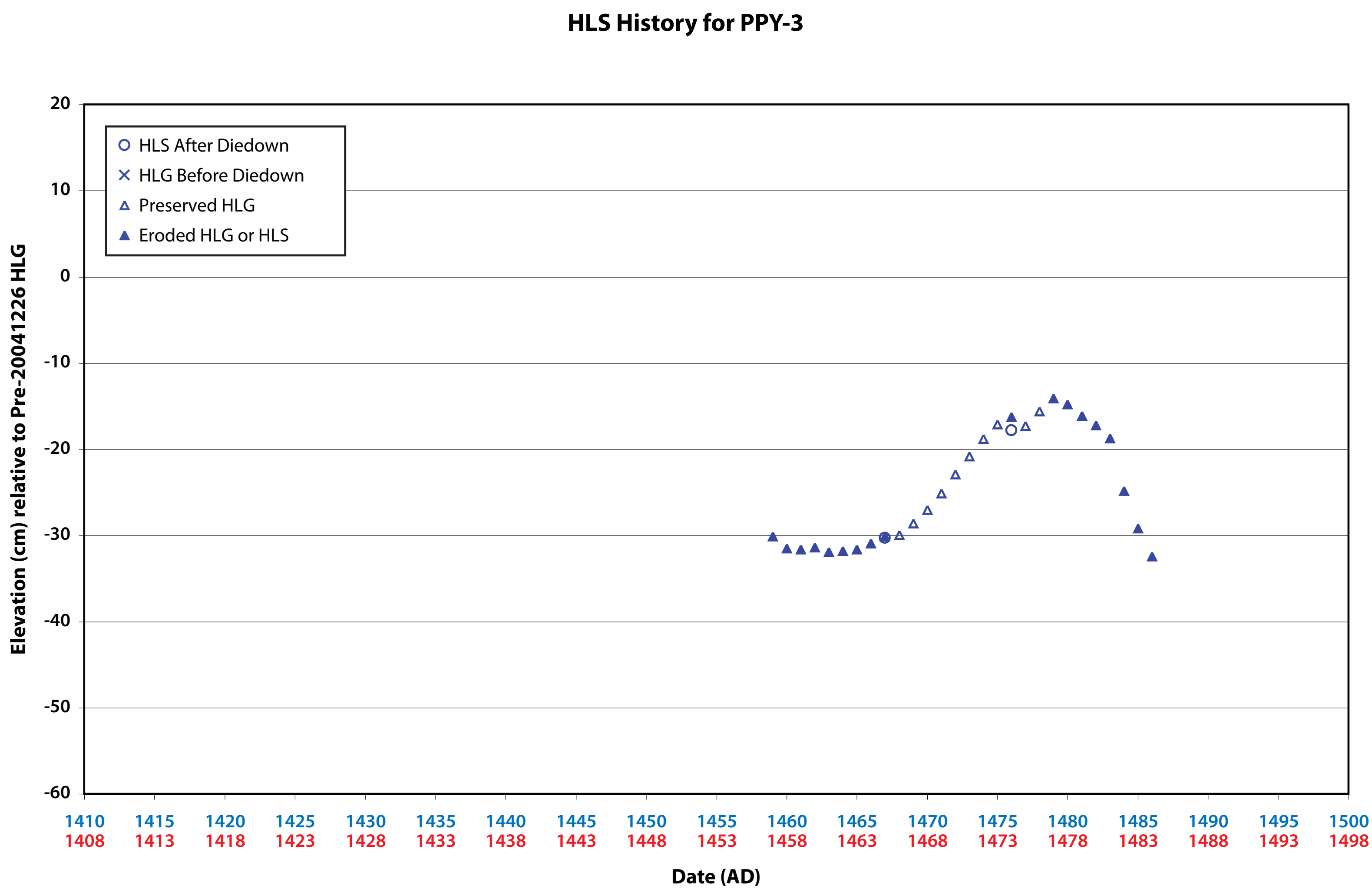

Figure S16b. Relative sea level history derived from slab PPY-3.
On the horizontal axis, blue dates correspond to Scenario A, whereas red dates correspond to Scenario B. See text for discussion.

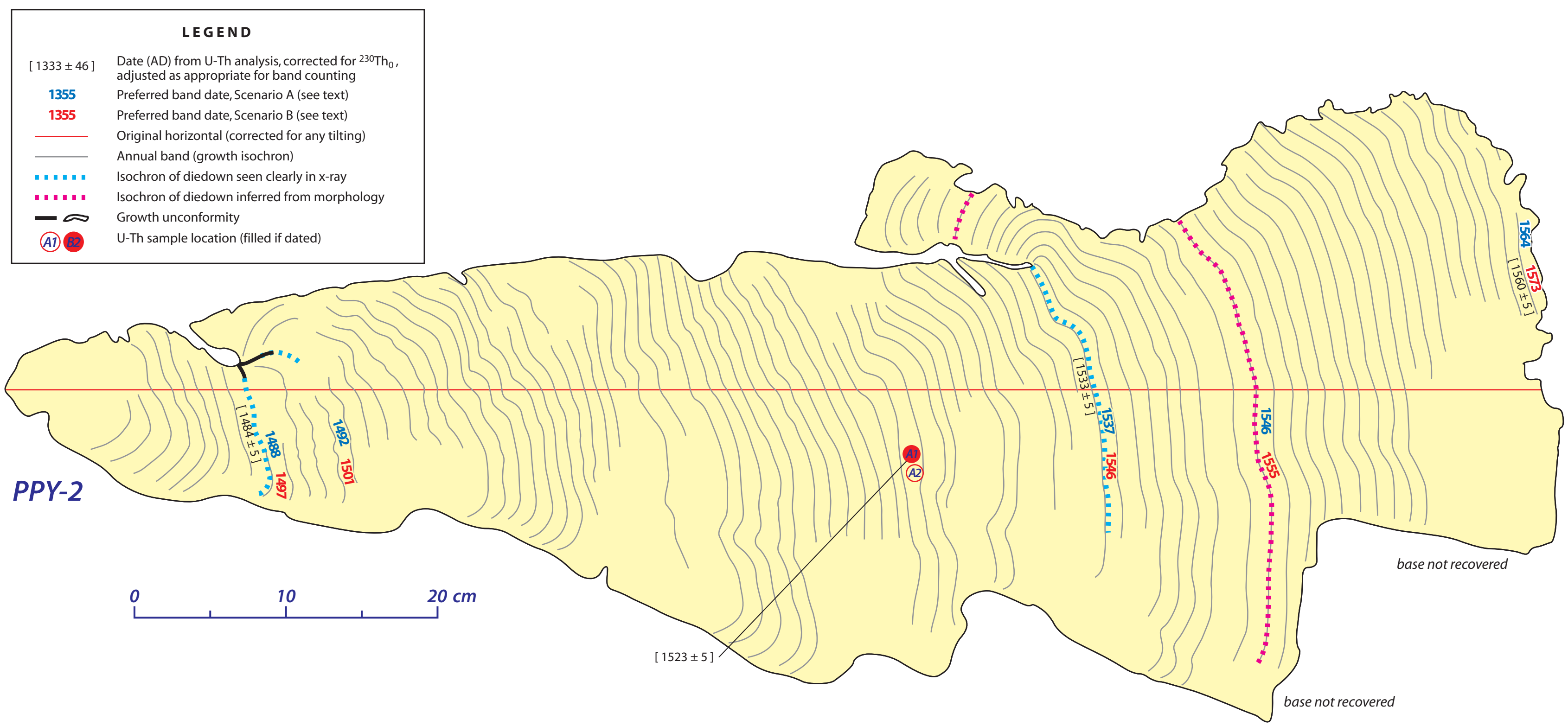

Figure S17a. Cross-section of slab PPY-2, from site PPY-A.

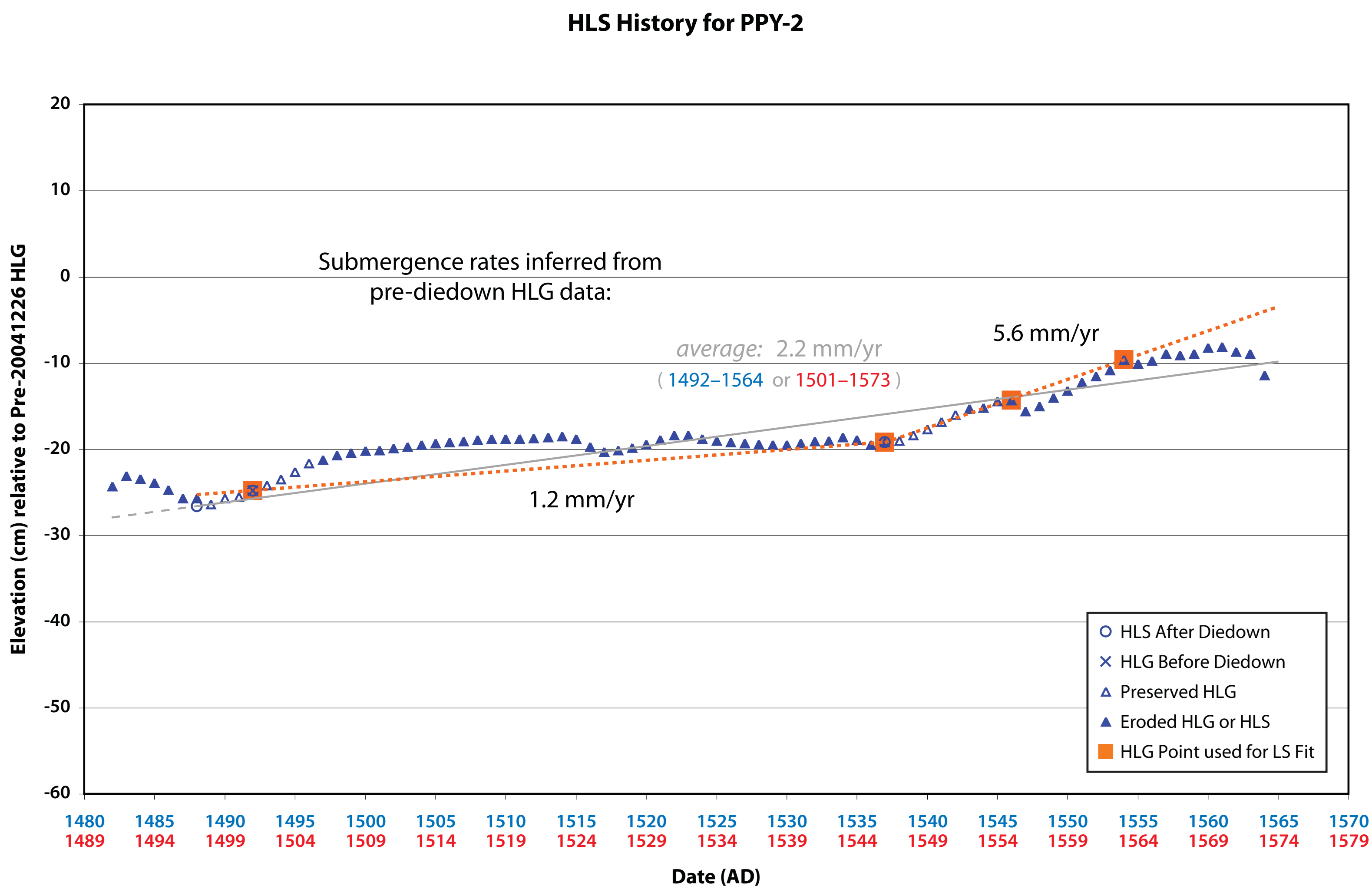

Figure S17b. Relative sea level history derived from slab PPY-2.
On the horizontal axis, blue dates correspond to Scenario A, whereas red dates correspond to Scenario B. See text for discussion.

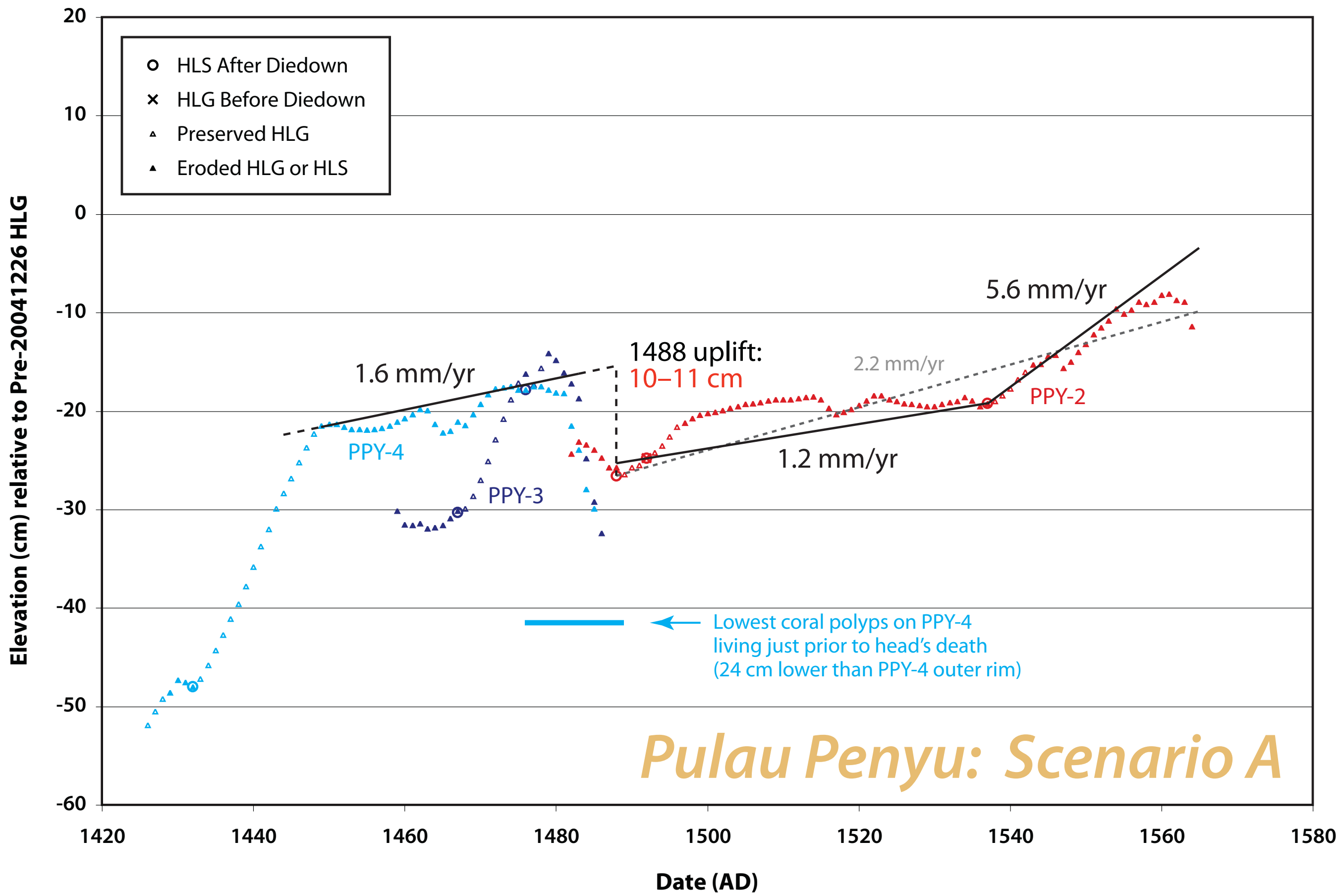

Figure S18a. Relative sea level history (Scenario A, assuming the first diedown on PPY-2 corresponds to the death of PPY-3 and PPY-4) for the 15th–16th centuries at site PPY-A. The sea level curve is solid where well constrained by data, dotted where averaged over long periods, and dashed where inferred.

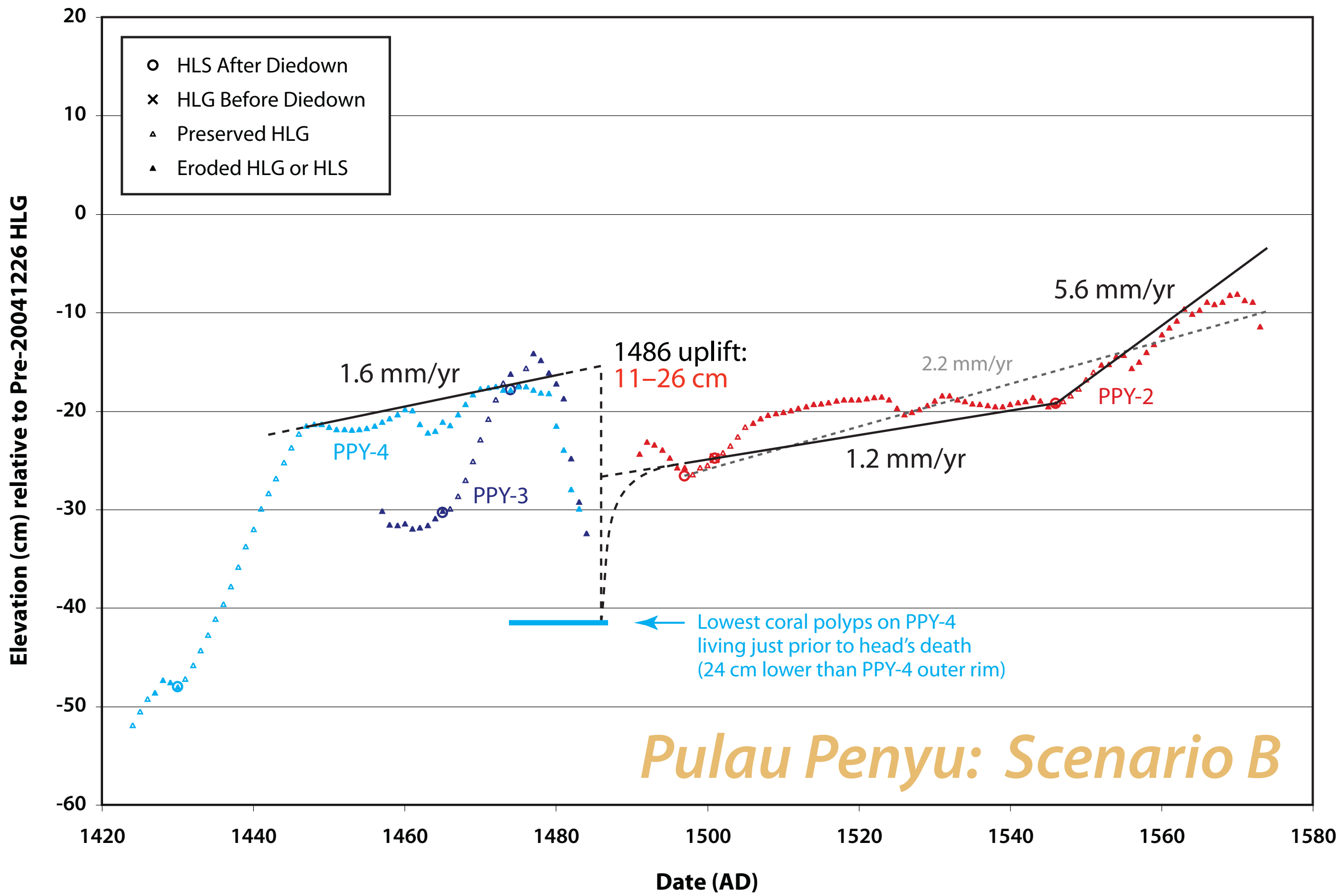

Figure S18b. Relative sea level history (Scenario B, assuming PPY-2 entirely post-dates PPY-3 and PPY-4) for the 15th–16th centuries at PPY-A. The sea level curve is solid where well constrained by data, dotted where averaged over long periods, and dashed where inferred.

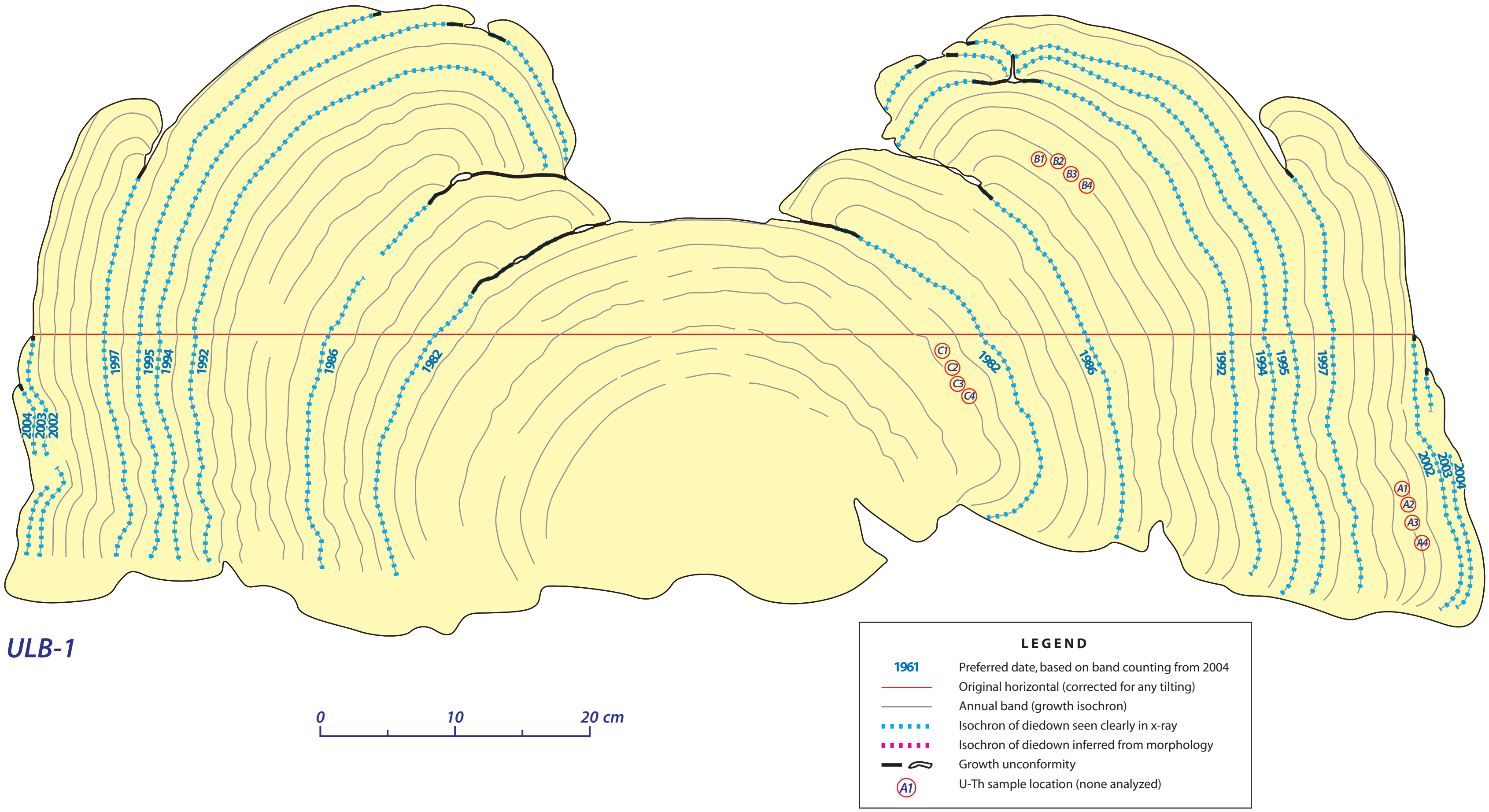

Figure S19a. Cross-section of slab ULB-1, from site ULB-A.

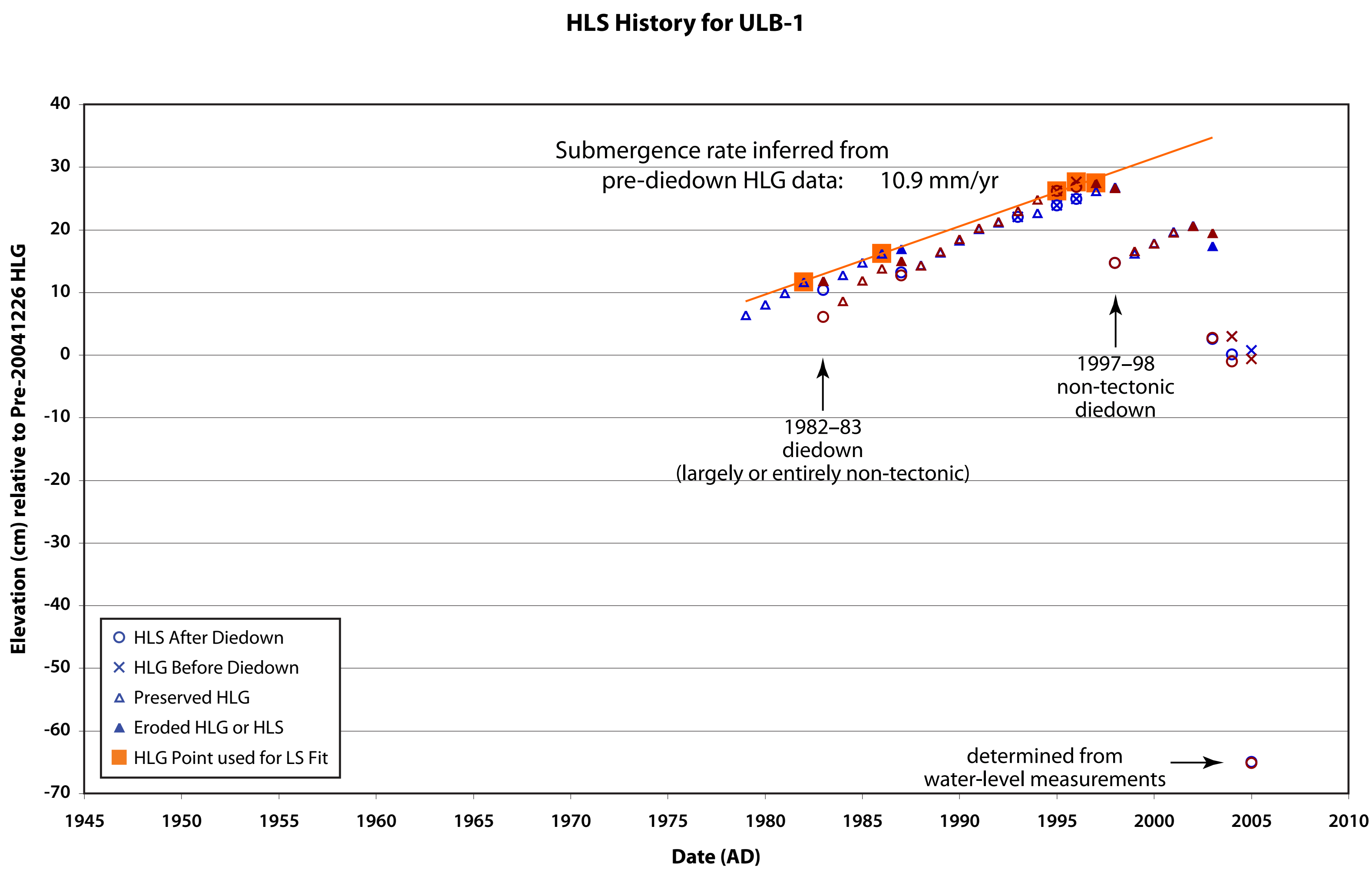

Figure S19b. Relative sea level history derived from slab ULB-1. Elevations given relative to averaged pre-2004/12/26 HLG on ULB-1.

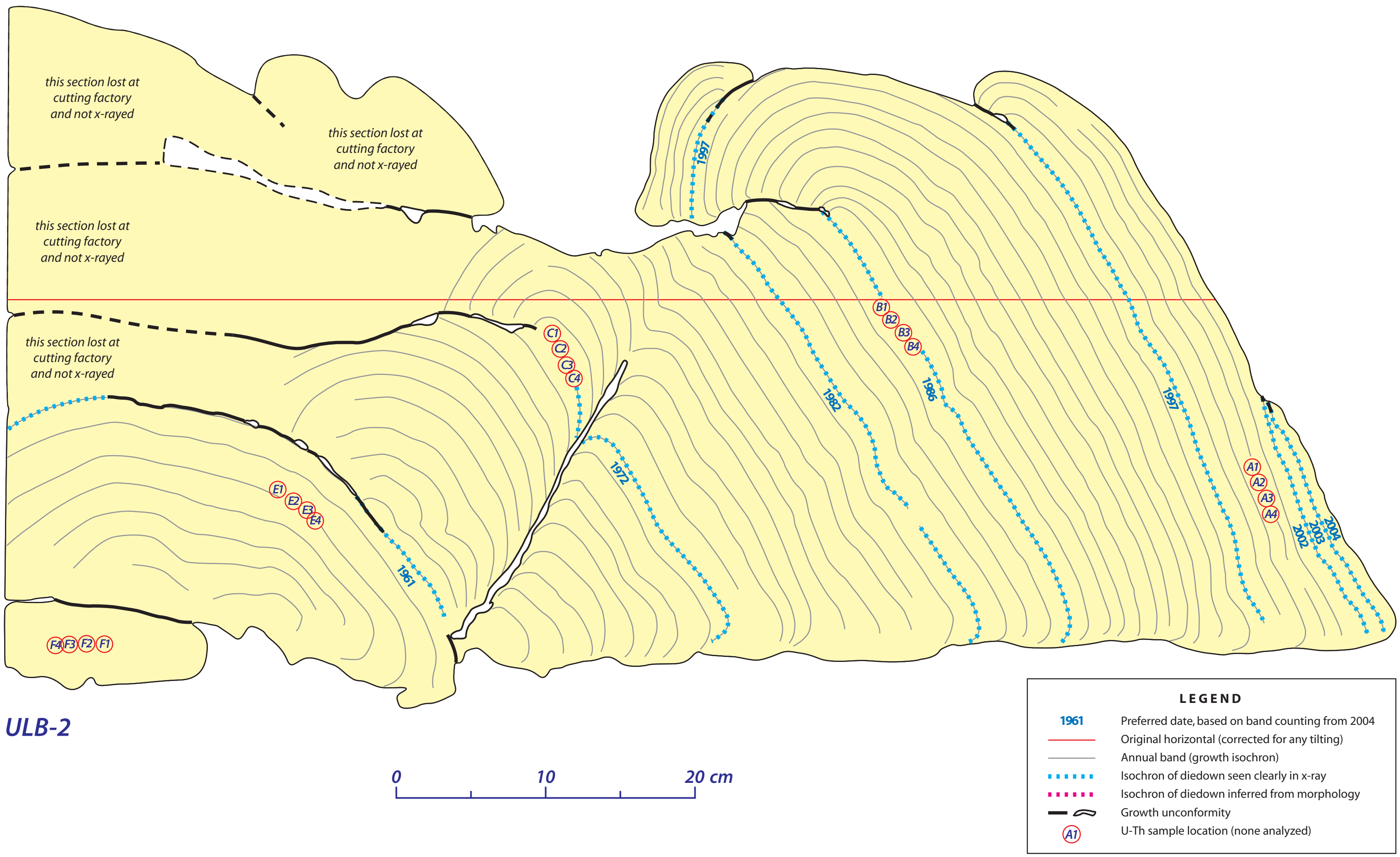

Figure S20a. Cross-section of slab ULB-2, from site ULB-A.

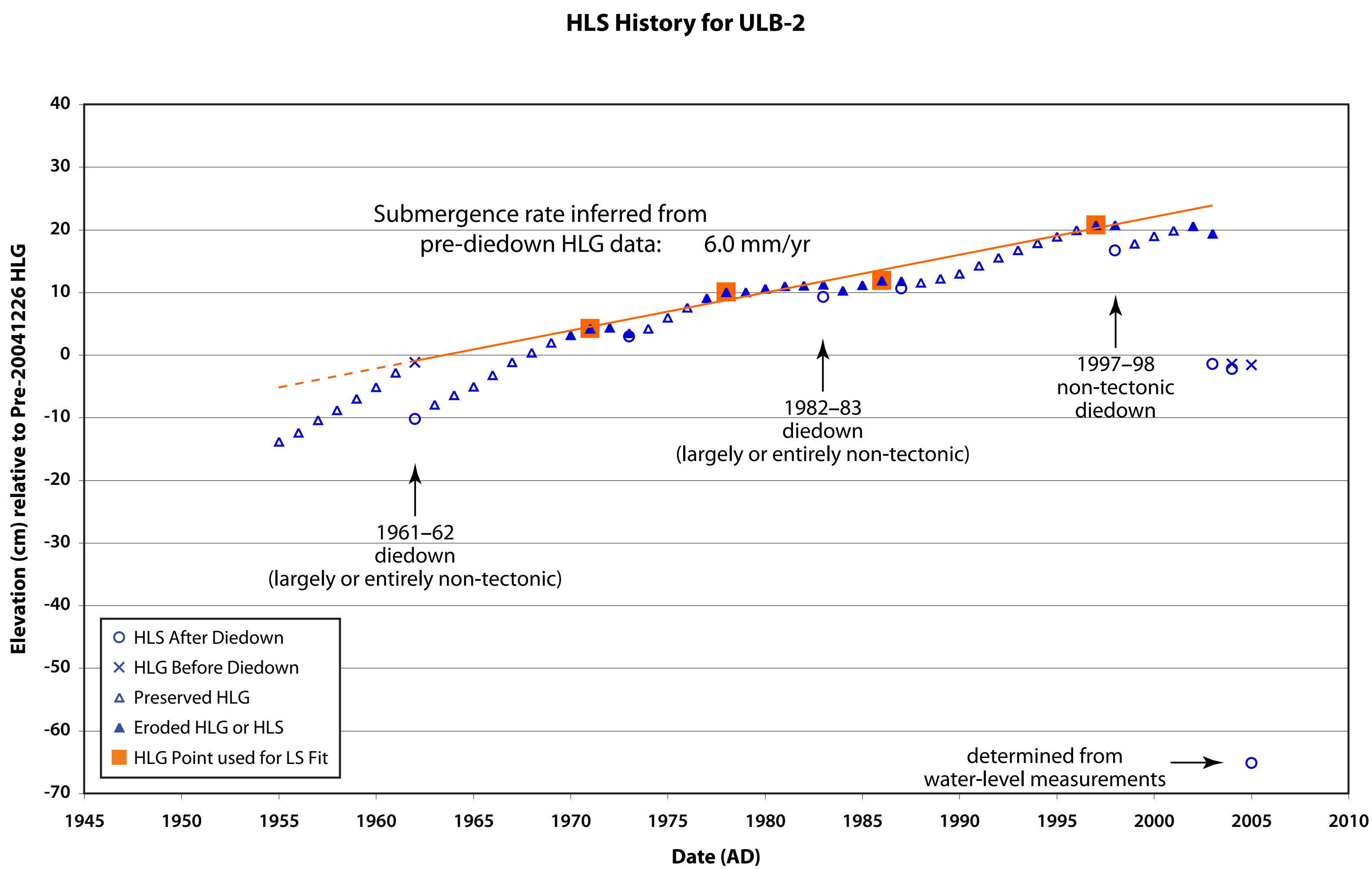

Figure S20b. Relative sea level history derived from slab ULB-2. Elevations given relative to averaged pre-2004/12/26 HLG on ULB-1.

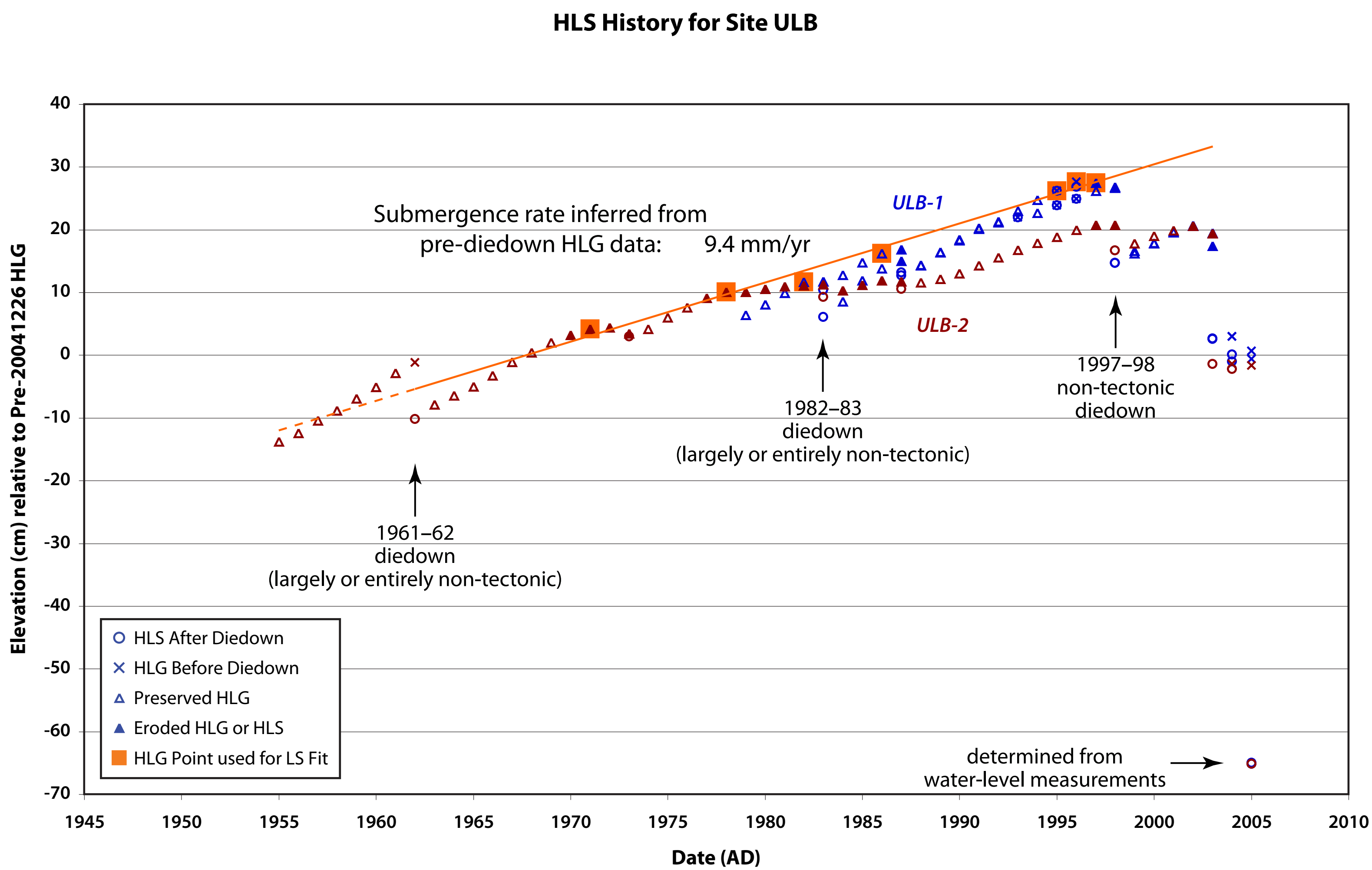

Figure S21. Relative sea level history derived jointly from ULB-1 and ULB-2. Elevations given relative to pre-2004/12/26 HLG on ULB-1.

Head Name	Site Name	Collected	Latitude	Longitude	Mod/Fsl	Genus
BUN-1	BUN-A	Jun 2006	2.51294	96.14433	Modern	*Porites*
BUN-2	BUN-A	Jun 2006	2.51291	96.14427	Modern	*Porites*
BUN-3	BUN-A	Jun 2006	2.51513	96.14477	Fossil	*Porites*
BUN-4	BUN-A	Jul 2007	2.51357	96.14387	Fossil	*Porites*
BUN-5	BUN-A	Jul 2007	2.51358	96.14391	Fossil	*Porites*
BUN-6	BUN-A	Jul 2007	2.51305	96.14423	Fossil	*Porites*
BUN-7	BUN-A	Jul 2007	2.51338	96.14327	Fossil	*Porites*
BUN-8	BUN-A	Jul 2007	2.51335	96.14339	Fossil	*Porites*
BUN-9	BUN-A	Jul 2007	2.51297	96.14333	Fossil	*Porites*
BUN-10	BUN-B	Jan 2009	2.51870	96.12891	Modern	*Porites*
PPY-1	PPY-A	Jul 2007	2.85309	95.94407	Modern	*Porites*
PPY-2	PPY-A	Jul 2007	2.85527	95.94304	Fossil	*Porites*
PPY-3	PPY-A	Jul 2007	2.85518	95.94286	Fossil	*Porites*
PPY-4	PPY-A	Jul 2007	2.85522	95.94229	Fossil	*Porites*
ULB-1	ULB-A	Jun 2006	2.56620	95.99508	Modern	*Porites*
ULB-2	ULB-A	Jun 2006	2.56609	95.99531	Modern	*Porites*

Uranium and Thorium isotopic compositions and ^{230}Th ages for Sumatran coral samples by MC-ICP-MS **Table S2**

Sample ID	Weight g	^{238}U ppb	^{232}Th ppt	δ^{234}U measured [a]	[^{230}Th/^{238}U] activity [c]	[^{230}Th/^{232}Th] (x 10^{-6}) [d]	$\delta^{234}U_{initial}$ corrected [b]	^{230}Th Age uncorrected	^{230}Th Age corrected [c,e]	Chemistry Date (AD)	Chemistry Date (AD)	Date (AD) of Sample Growth	[^{230}Th/^{232}Th]$_0$ (x 10^{-6}) [e]
BUN-3-A2	0.107	2050 ± 2	537 ± 7	143.8 ± 1.6	0.00500 ± 0.00006	315.5 ± 5.3	144.0 ± 1.6	478.6 ± 5.6	469 ± 11	2009/11/20	2009.9	**1541.1 ± 11.3**	6.5 ± 6.5
BUN-3-B2 (1)	0.641	1821 ± 3	1529 ± 3	142.9 ± 2.1	0.00547 ± 0.00008	107.7 ± 1.6	143.1 ± 2.1	524.2 ± 7.8	465 ± 42	2006/12/21	2007.0	**1542.0 ± 42.0**	10.8 ± 11.9
BUN-3-B2 (2)	0.810	2075 ± 5	813 ± 3	142.1 ± 2.9	0.00525 ± 0.00010	221.3 ± 4.4	142.3 ± 2.9	503 ± 10	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-3-B2 (3)	0.571	1999 ± 3	912 ± 2	145.8 ± 1.9	0.00517 ± 0.00008	186.9 ± 2.9	146.0 ± 1.9	493.3 ± 7.7					
BUN-3-B2 (4)	0.434	2179 ± 3	1241 ± 3	145.8 ± 2.0	0.00519 ± 0.00007	150.3 ± 1.9	146.0 ± 2.0	495.3 ± 6.4					
BUN-3-C3	0.095	2743 ± 2	1084 ± 7	146.1 ± 1.3	0.00538 ± 0.00005	224.6 ± 2.6	146.3 ± 1.3	513.4 ± 4.8	499 ± 16	2009/11/20	2009.9	**1511.3 ± 15.6**	6.5 ± 6.5
BUN-3-D2	0.093	2168 ± 1	3344 ± 9	145.2 ± 1.5	0.00568 ± 0.00007	60.8 ± 0.8	145.4 ± 1.5	543.2 ± 6.9	485 ± 58	2009/11/20	2009.9	**1524.6 ± 58.3**	6.5 ± 6.5
BUN-3-E3	0.093	2339 ± 1	4567 ± 10	145.6 ± 1.5	0.00614 ± 0.00008	51.9 ± 0.7	145.8 ± 1.5	587.0 ± 7.3	514 ± 74	2009/11/20	2009.9	**1496.1 ± 73.7**	6.5 ± 6.5
BUN-3-F3	0.104	2708 ± 2	1957 ± 7	146.2 ± 1.4	0.00598 ± 0.00005	136.6 ± 1.3	146.5 ± 1.4	570.8 ± 5.2	544 ± 28	2009/11/20	2009.9	**1466.1 ± 27.6**	6.5 ± 6.5
BUN-4-A1	0.102	1857 ± 2	1842 ± 8	144.8 ± 1.5	0.00507 ± 0.00008	84.4 ± 1.4	145.0 ± 1.5	484.6 ± 7.8	447 ± 38	2007/10/24	2007.8	**1560.5 ± 38.1**	6.5 ± 6.5
BUN-5-A1	0.101	2513 ± 2	1511 ± 8	145.4 ± 1.5	0.00641 ± 0.00006	176.2 ± 1.9	145.7 ± 1.5	613.1 ± 5.9	591 ± 23	2007/10/24	2007.8	**1417.2 ± 23.3**	6.5 ± 6.5
BUN-6-A1	0.119	2183 ± 2	359 ± 6	144.4 ± 1.5	0.00636 ± 0.00006	638 ± 12	144.6 ± 1.5	608.2 ± 5.5	602.0 ± 8.3	2007/10/24	2007.8	**1405.8 ± 8.3**	6.5 ± 6.5
BUN-6-B1	0.100	2352 ± 4	1301 ± 4	145.5 ± 2.6	0.00640 ± 0.00005	190.8 ± 1.4	145.7 ± 2.6	611.3 ± 4.6	591 ± 21	2008/10/13	2008.8	**1418.2 ± 21.3**	6.5 ± 6.5
BUN-6-B2	0.100	2450 ± 2	1421 ± 7	145.8 ± 1.4	0.00645 ± 0.00006	183.7 ± 1.8	146.1 ± 1.4	616.6 ± 5.4	595 ± 22	2009/11/20	2009.9	**1415.0 ± 22.4**	6.5 ± 6.5
										weight-averaged age		***1416.7 ± 15.4***	
BUN-7-A1	0.100	2418 ± 2	664 ± 7	143.9 ± 1.2	0.00658 ± 0.00007	395.7 ± 5.9	144.1 ± 1.2	630.1 ± 6.4	620 ± 12	2007/10/24	2007.8	**1388.0 ± 12.1**	6.5 ± 6.5
BUN-7-B2	0.115	2090 ± 3	1962 ± 5	145.4 ± 2.2	0.00703 ± 0.00006	123.7 ± 1.1	145.7 ± 2.2	672.3 ± 5.9	637 ± 36	2008/10/13	2008.8	**1371.7 ± 35.7**	6.5 ± 6.5
BUN-7-C2 (1)	0.094	2460 ± 4	5328 ± 14	147.0 ± 2.2	0.00779 ± 0.00009	59.4 ± 0.7	147.3 ± 2.2	744.5 ± 8.7	663 ± 82	2008/10/13	2008.8	1345.5 ± 81.7	6.5 ± 6.5
BUN-7-C2 (2)	0.101	2406 ± 4	5625 ± 15	143.1 ± 2.3	0.00784 ± 0.00009	55.4 ± 0.7	143.3 ± 2.3	751.2 ± 9.1	663 ± 88	2008/10/13	2008.8	1345.5 ± 88.4	6.5 ± 6.5
BUN-7-C2 (3)	0.102	2469 ± 3	5925 ± 14	143.1 ± 2.3	0.00789 ± 0.00009	54.3 ± 0.6	143.3 ± 2.3	756.2 ± 8.7	666 ± 91	2008/10/13	2008.8	1342.9 ± 90.7	6.5 ± 6.5
BUN-7-C2 (4)	0.125	2512 ± 6	6154 ± 14	150.5 ± 2.9	0.00786 ± 0.00009	53.0 ± 0.6	150.7 ± 2.9	748.6 ± 8.7	657 ± 92	2008/10/13	2008.8	1351.8 ± 92.0	6.5 ± 6.5
										weight-averaged age		***1346.3 ± 44.0***	
BUN-8-A2 (1)	0.092	3049 ± 3	4082 ± 12	144.9 ± 1.5	0.00629 ± 0.00007	77.6 ± 0.9	145.1 ± 1.5	601.9 ± 7.0	569 ± 15	2007/10/24	2007.8	**1438.8 ± 15.0**	4.2 ± 1.5
BUN-8-A2 (2)	0.090	2925 ± 5	4316 ± 13	144.2 ± 2.5	0.00633 ± 0.00007	70.8 ± 0.8	144.4 ± 2.5	605.7 ± 6.8	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-8-A2 (3)	0.102	3098 ± 5	7373 ± 21	144.1 ± 2.4	0.00656 ± 0.00008	45.5 ± 0.5	144.3 ± 2.4	627.7 ± 7.4					
BUN-8-A2 (4)	0.118	2890 ± 5	4742 ± 12	144.7 ± 2.6	0.00638 ± 0.00007	64.2 ± 0.7	145.0 ± 2.6	610.5 ± 6.5					
BUN-8-C1 (1)	0.097	2925 ± 4	10245 ± 26	146.5 ± 2.2	0.00618 ± 0.00010	29.1 ± 0.5	146.7 ± 2.2	589.8 ± 9.4	568 ± 23	2008/10/13	2008.8	**1440.8 ± 23.0**	1.2 ± 1.0
BUN-8-C1 (2)	0.094	2966 ± 3	16767 ± 48	146.5 ± 1.7	0.00634 ± 0.00013	18.5 ± 0.4	146.8 ± 1.7	606 ± 12	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-8-C1 (3)	0.123	2850 ± 3	9016 ± 22	147.2 ± 1.7	0.00617 ± 0.00009	32.2 ± 0.5	147.4 ± 1.7	589.0 ± 8.9					
BUN-8-C1 (4)	0.106	2848 ± 4	10800 ± 28	147.9 ± 2.1	0.00625 ± 0.00009	27.2 ± 0.4	148.1 ± 2.1	596.0 ± 8.6					
BUN-9A-A1	0.111	2476 ± 3	833 ± 7	146.2 ± 1.6	0.01060 ± 0.00007	519.7 ± 5.2	146.6 ± 1.6	1,014.2 ± 6.4	1,002 ± 14	2007/10/24	2007.8	**1006.2 ± 14.2**	6.5 ± 6.5
BUN-9D-A2 (1)	0.099	2677 ± 2	22731 ± 93	145.0 ± 1.4	0.01263 ± 0.00024	24.6 ± 0.5	145.3 ± 1.4	1,211 ± 23	1,150 ± 44	2007/10/24	2007.8	**857.8 ± 44.0**	1.6 ± 1.4
BUN-9D-A2 (2)	0.083	2567 ± 4	21109 ± 66	145.9 ± 2.5	0.01292 ± 0.00018	25.9 ± 0.4	146.3 ± 2.6	1,238 ± 17	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-9D-A2 (3)	0.097	2449 ± 5	32700 ± 134	147.0 ± 2.7	0.01331 ± 0.00025	16.5 ± 0.3	147.4 ± 2.7	1,274 ± 24					
BUN-9D-A2 (4)	0.126	2636 ± 5	37697 ± 188	144.2 ± 2.5	0.01344 ± 0.00028	15.5 ± 0.3	144.5 ± 2.5	1,290 ± 27					
PPY-2-A1	0.209	2852 ± 3	264 ± 3	148.5 ± 1.9	0.00513 ± 0.00003	915 ± 13	148.7 ± 1.9	488.5 ± 3.2	485.1 ± 4.7	2007/10/22	2007.8	**1522.7 ± 4.7**	6.5 ± 6.5
PPY-3-A1	0.274	2424 ± 2	219 ± 3	146.9 ± 1.2	0.00553 ± 0.00003	1,012 ± 13	147.2 ± 1.2	528.1 ± 2.7	524.7 ± 4.4	2007/10/22	2007.8	**1483.1 ± 4.4**	6.5 ± 6.5
PPY-4-A1	0.190	2718 ± 2	582 ± 4	145.8 ± 1.4	0.00563 ± 0.00003	433.9 ± 3.9	146.0 ± 1.4	537.5 ± 3.2	529.5 ± 8.7	2007/10/22	2007.8	**1478.3 ± 8.7**	6.5 ± 6.5

Uranium and Thorium isotopic compositions and ^{230}Th ages for Sumatran coral samples by MC-ICP-MS — Table S2

For a discussion of the MC-ICP-MS method, see *Shen et al.* [2002, 2010]. Analytical errors are 2σ of the mean.

[a] $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$.

[b] $\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured}\ X\ e^{\lambda 234*T}$, and T is corrected age.

[c] $[^{230}Th/^{238}U]_{activity} = 1 - e^{-\lambda 230\,T} + (\delta^{234}U_{measured}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda 230 - \lambda 234)\,T})$, where T is the age.

Decay constants are 9.1577×10^{-6} yr^{-1} for ^{230}Th, 2.8263×10^{-6} yr^{-1} for ^{234}U, and 1.55125×10^{-10} yr^{-1} for ^{238}U [*Jaffey et al.*, 1971; *Cheng et al.*, 2000].

[d] The degree of detrital ^{230}Th contamination is indicated by the [^{230}Th/^{232}Th] atomic ratio instead of the activity ratio.

[e] Except where isochron techniques were used to determine the ages and initial ^{230}Th/^{232}Th atomic ratios, the initial ^{230}Th/^{232}Th atomic ratio is assumed to be $6.5 \pm 6.5 \times 10^{-6}$ [*Zachariasen et al*., 1999].

Dates of Presumed Uplift of Individual Coral Heads **Table S3**

Sample ID	Date of Sample (AD)	Preserved Bands after Sample	Date of Outer Band (AD)	Slab Weighted Mean Date of Outer Band	Inferred Number of Missing Bands	Slab Weighted Mean Date of Coral Death	Outer Rim Elevation (cm) above Pre-20041226 HLG
BUN-3-A2	1541.1 ± 11.3	18.0 ± 0.5	1559.1 ± 11.3	**1565.6 ± 8.4**	2.0 ± 2.0	1567.6 ± 8.6	56.7 outer rim; tilted and settled **
BUN-3-B2	1542.0 ± 42.0	26.5 ± 0.5	1568.5 ± 42.0				
BUN-3-C3	1511.3 ± 15.6	58.5 ± 0.5	1569.8 ± 15.6				
BUN-3-D2	1524.6 ± 58.3	75.5 ± 0.5	1600.1 ± 58.3				
BUN-3-E3	1496.1 ± 73.7	95.5 ± 0.5	1591.6 ± 73.7				
BUN-3-F3	1466.1 ± 27.6	112.0 ± 0.5	1578.1 ± 27.6				
BUN-4-A1	1560.5 ± 38.1	14.5 ± 0.5	1575.0 ± 38.1	**1575.0 ± 38.1**	38.5 ± 2.0	1613.5 ± 38.1	66.4 inner of double rim
BUN-5-A1	1417.2 ± 23.3	18.5 ± 0.5	1435.7 ± 23.3	**1435.7 ± 23.3**	2.0 ± 2.0	1437.7 ± 23.4	76.3 where less eroded
BUN-6-A1	1405.8 ± 8.3	55.0 ± 0.5	1460.8 ± 8.3	**1473.2 ± 7.3**	5.0 ± 5.0 *	1478.2 ± 8.9 *	-5.8 outermost rim; fairly eroded
BUN-6-B1/2	1416.7 ± 15.4	99.5 ± 0.5	1516.2 ± 15.4				
BUN-7-A1	1388.0 ± 12.1	31.0 ± 0.5	1419.0 ± 12.2	**1423.0 ± 11.1**	2.0 ± 2.0	1425.0 ± 11.3	76.0 crown of outer rim has sustained erosion; tilted
BUN-7-B2	1371.7 ± 35.7	64.5 ± 0.5	1436.2 ± 35.7				
BUN-7-C2	1346.3 ± 44.0	109.0 ± 0.5	1455.3 ± 44.0				
BUN-8-A2	1438.8 ± 15.0	52.5 ± 0.5	1491.3 ± 15.0	**1479.4 ± 12.6**	5.0 ± 5.0 *	1484.4 ± 13.5 *	9.1 outer preserved rim; settled **
BUN-8-C1	1440.8 ± 23.0	10.5 ± 0.5	1451.3 ± 23.0				
BUN-9A-A1	1006.2 ± 14.2	12.0 ± 0.5	1018.2 ± 14.2	**1019.0 ± 13.7**	5.0 ± 5.0	1024.0 ± 14.5	-6.3 outer rim; tilted, fairly eroded
BUN-9D-A2	857.8 ± 44.0	171.0 ± 25.0	1028.8 ± 50.6				
PPY-2-A1	1522.7 ± 4.7	39.0 ± 0.5	1561.7 ± 4.7	**1561.7 ± 4.7**	2.0 ± 2.0	1563.7 ± 5.1	-7.7 outer rim
PPY-3-A1	1483.1 ± 4.4	5.0 ± 0.5	1488.1 ± 4.4	**1488.1 ± 4.4**	2.0 ± 2.0	1490.1 ± 4.8	-17.8 outer ring; tilted **
PPY-4-A1	1478.3 ± 8.7	12.5 ± 0.5	1490.8 ± 8.7	**1490.8 ± 8.7**	2.5 ± 2.0	1493.3 ± 8.9	-17.4 outer of double ring

* *Although BUN-6 and BUN-8 are each listed as missing 5 ± 5 outer bands, the real number may be much higher. The outer part of each of those heads was very thin; it is possible that tens of bands or even >100 additional bands originally grew, but broke off and were subsequently transported away. Also, either of those heads may have plausibly died for reasons other than a tectonic diedown, considering their thin perimeters.*

** *The stated elevations are those measured in the field; for tilted heads, they are averaged over as much of the head as possible.*
The original pre-tilting and pre-settling elevation of BUN-3 can be determined by comparison with BUN-4; see text for details.
The original pre-settling elevation of BUN-8 can be determined by comparison with BUN-7 and other surveyed heads; see text for details.
The original pre-tilting elevation of PPY-3 can be determined by comparison with PPY-4; see text for details.

Pre-Historical Event	Site	Head	Date of Tectonic Diedown (AD) Per Head	Site Avg	All-Site Avg
Bunon: AD 1420s–1430s *(assuming a single ~1430 diedown ; also assuming the first diedown on BUN-3 occurred 50 ± 5 years after the ~1430 diedown)*	BUN BUN BUN BUN	BUN-5 BUN-7 BUN-8 BUN-3	1437.7 ± 23.4 1425.0 ± 11.3 1434.9 ± 12.6 [a] 1410.1 ± 9.8 [c]	**1422.3 ± 6.1**	**1422.3 ± 6.1**
Bunon: AD 1420s–1430s *(assuming dual ~1430 diedowns; this is the date of the first/larger of the two; also assuming the first diedown on BUN-3 occurred 50 ± 5 years after the latter ~1430 diedown)*	BUN BUN BUN BUN	BUN-5 BUN-7 BUN-8 BUN-3	1437.7 ± 23.4 1425.0 ± 11.3 1426.9 ± 12.7 [b] 1402.1 ± 10.0 [d]	**1417.4 ± 6.2**	**1417.4 ± 6.2**
P. Penyu: late 15th century AD *(assuming the first diedown on PPY-2 is what killed PPY-3 and PPY-4)*	PPY PPY PPY	PPY-2 PPY-3 PPY-4	1484.7 ± 4.7 [e] 1490.1 ± 4.8 1493.3 ± 8.9	**1488.1 ± 3.2**	**1488.1 ± 3.2**
P. Penyu: late 15th century AD *(assuming all of PPY-2 post-dates the death of PPY-3 and PPY-4)*	PPY PPY PPY	PPY-2 PPY-3 PPY-4	1473.7 ± 6.9 [f] 1490.1 ± 4.8 1493.3 ± 8.9	**1486.1 ± 3.6**	**1486.1 ± 3.6**
Bunon: latter 16th century AD	BUN BUN	BUN-3 BUN-4	1567.6 ± 8.6 1613.5 ± 38.1	**1569.8 ± 8.4**	**1565.4 ± 4.4**
P. Penyu: latter 16th century AD	PPY	PPY-2	1563.7 ± 5.1	**1563.7 ± 5.1**	

[a] *This date is 44.5 ± 0.5 years prior to the date of the outer edge of slab BUN-8.*
[b] *This date is 52.5 ± 2.0 years prior to the date of the outer edge of slab BUN-8.*

[c] *This date is 155.5 ± 5.0 years prior to the date of the outer edge of slab BUN-3.*
[d] *This date is 163.5 ± 5.4 years prior to the date of the outer edge of slab BUN-3.*

[e] *This date is 77.0 ± 0.5 years prior to the date of the outer edge of slab PPY-2.*
[f] *This date is 88.0 ± 5.0 years prior to the date of the outer edge of slab PPY-2.*